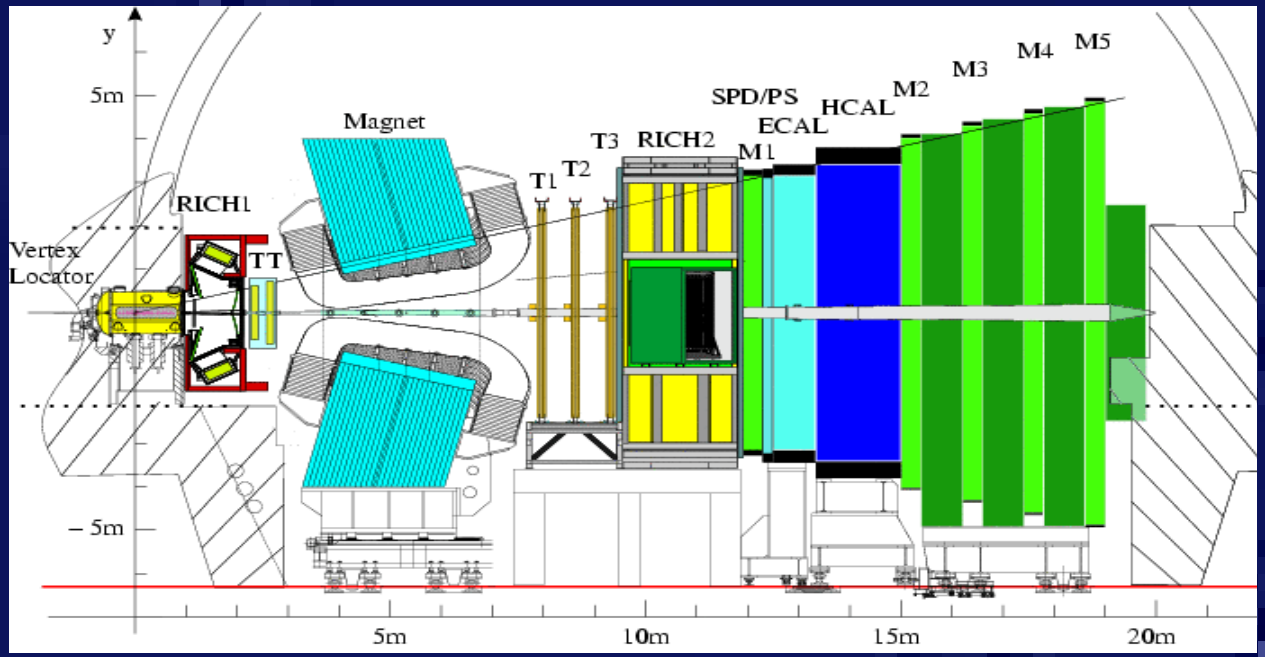
LHCb : Status and Commissioning



Gaia Lanfranchi
LNF - INFN
on behalf of the LHCb Collaboration

V Workshop Italiano sulla Fisica p-p a LHC – Perugia 2008

The Whole Idea

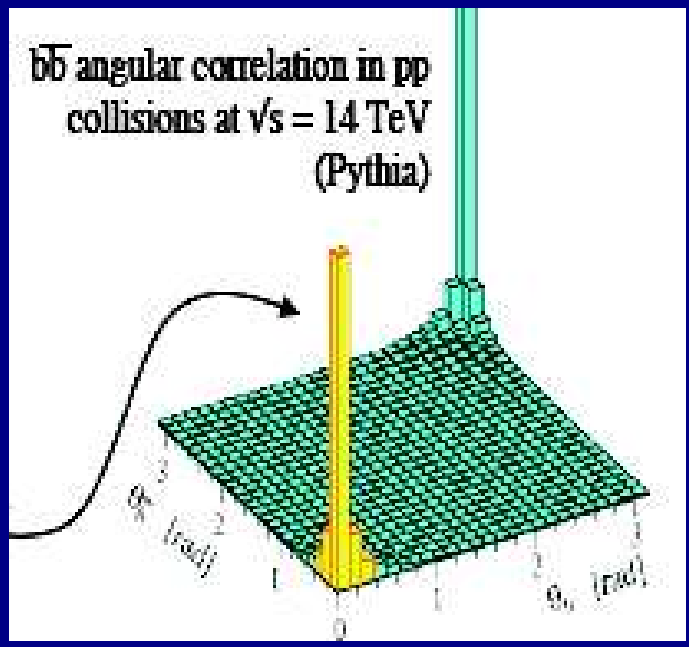
(since more than a decade)

♦ Given the fact that:

- LHC will be producing the largest number of b hadrons (of all types) by far, and for long time
- Tevatron experiments have demonstrated the feasibility of B physics at a hadron machine

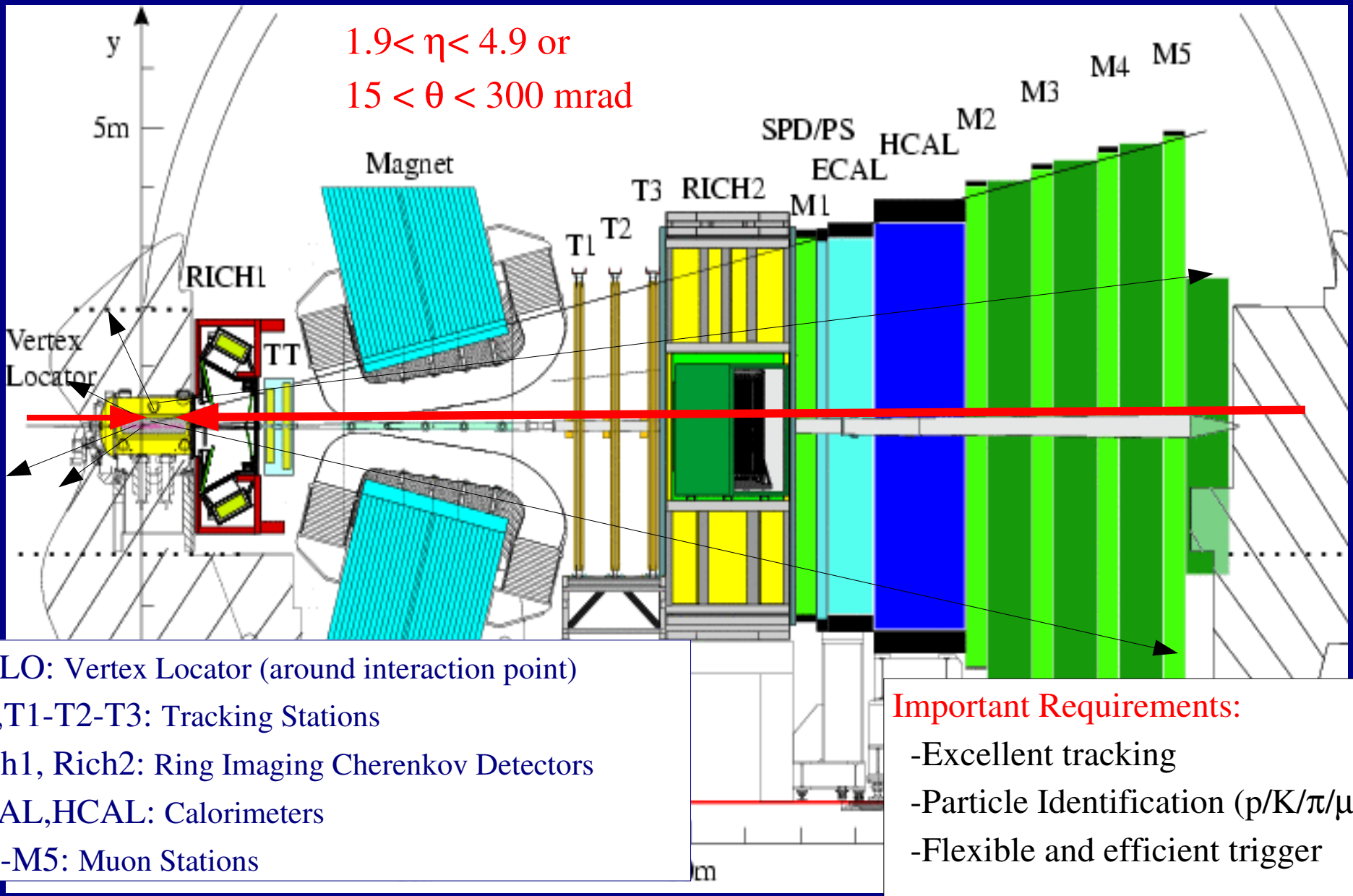
♦ Perform a dedicated B physics experiment at LHC, but with a new challenge:

- exploit the new bb production in the not-well-known forward region despite the "unfriendly" hadronic environment for B physics



~230 μbarn of bb production
in one of the forward peaks (~300 mrad)
corresponding to nearly 10^5 b hadrons per second
at a modest luminosity of 2×10^{32} cm^{-2} s^{-1}
with a small number of pp interaction per bunch crossing (n~0.4).

LHCb spectrometer



VELO: Vertex Locator (around interaction point)

TT,T1-T2-T3: Tracking Stations

Rich1, Rich2: Ring Imaging Cherenkov Detectors

ECAL,HCAL: Calorimeters

M1-M5: Muon Stations

Important Requirements:

-Excellent tracking

-Particle Identification (p/K/π/μ/e)

-Flexible and efficient trigger

LHCb at UX85

Calorimeters

Rich2

Magnet

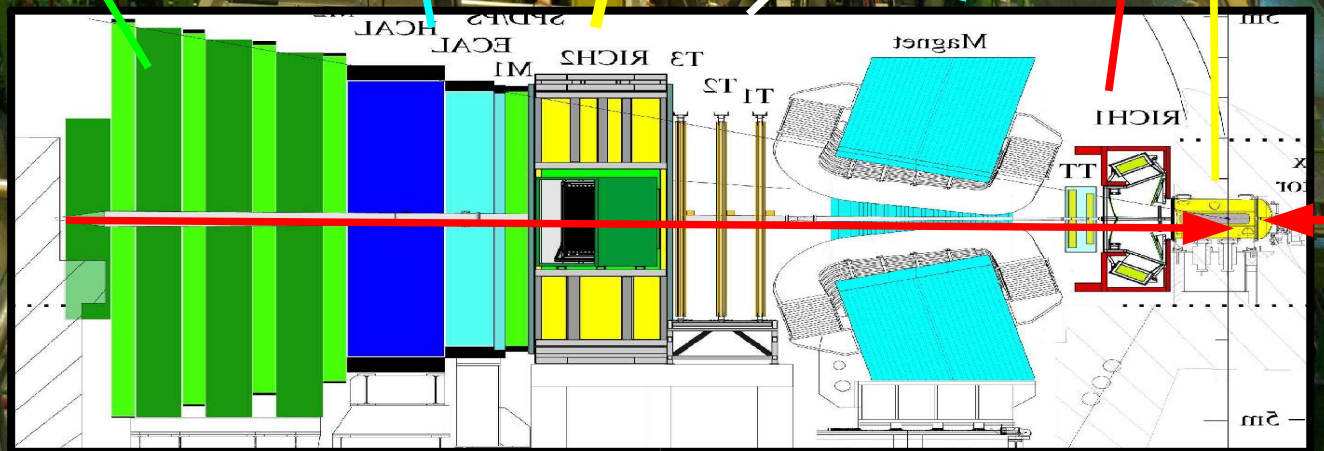
Rich1

Muons

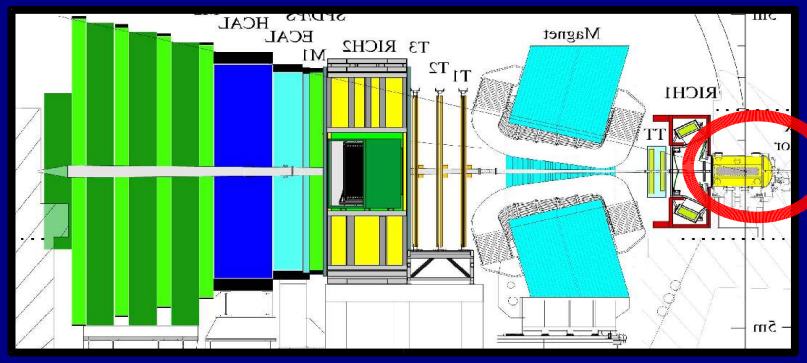
Outer & Inner

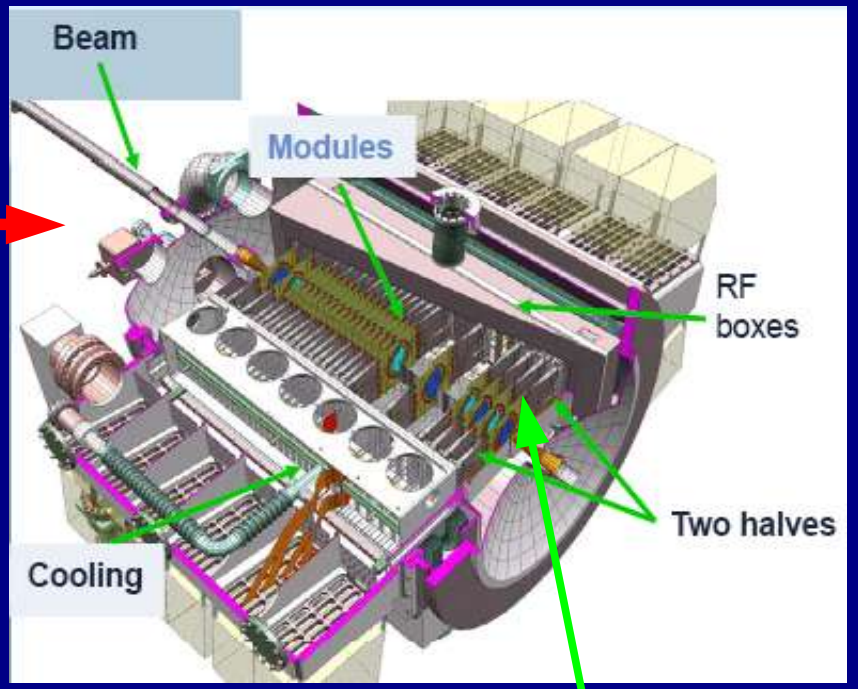
Tracker

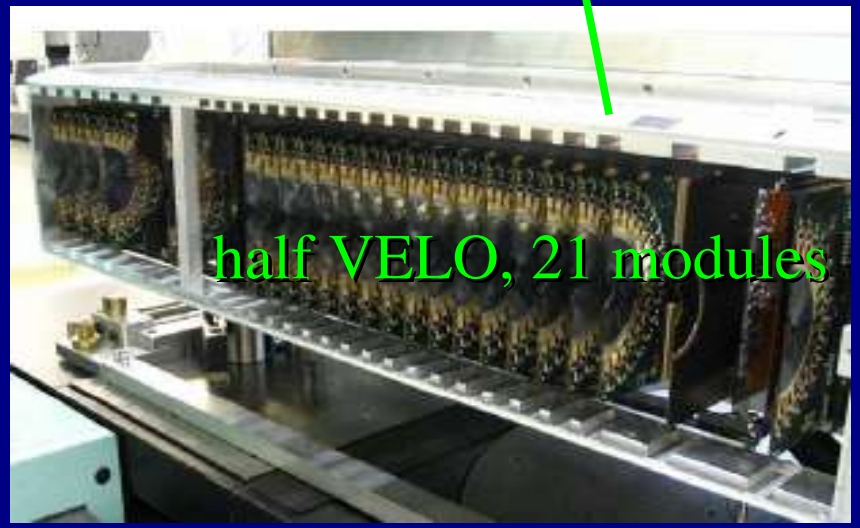
VELO



VErtex LOcator: structure







♦Structure:

- Two halves, 21 modules each:
- Placed 8 mm from beam,
  in a secondary vacuum vessel
- Separated by a 300 μm Al RF foil
  (constitutes the beam pipe in VELO region)

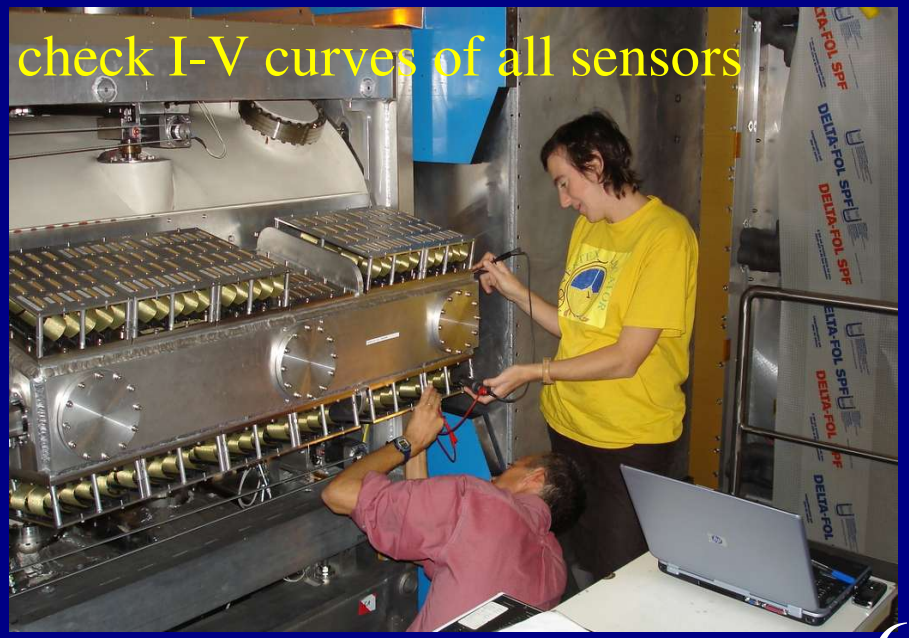
♦R-ϕ geometry optimized particles originating from beam-beam interactions:

- primary vertex resolution :
  ~50 μm in beam direction, ~10 μm in xy

VErtex LOcator: Status

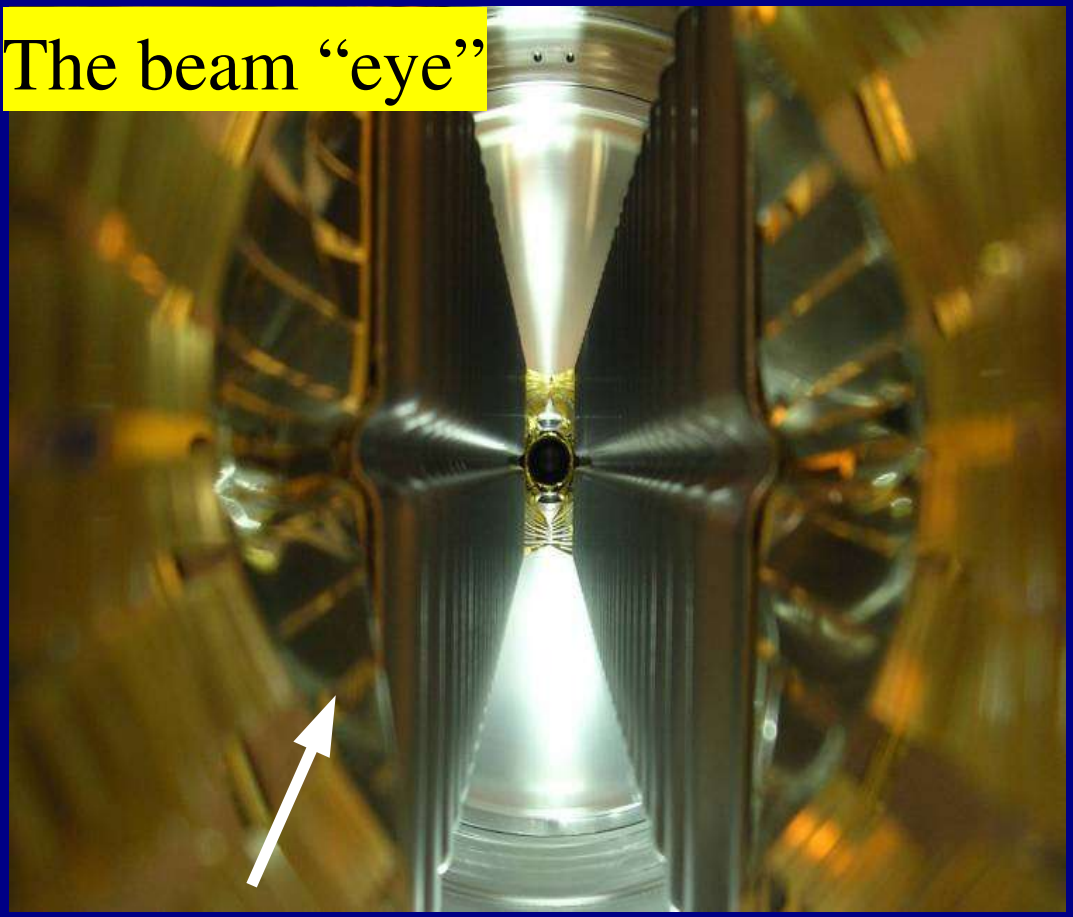
- Both halves installed in November 07
- Commissioning ongoing but hampered by Neon injection system being not fully automatic and by power supplies being late (CAEN LV system)

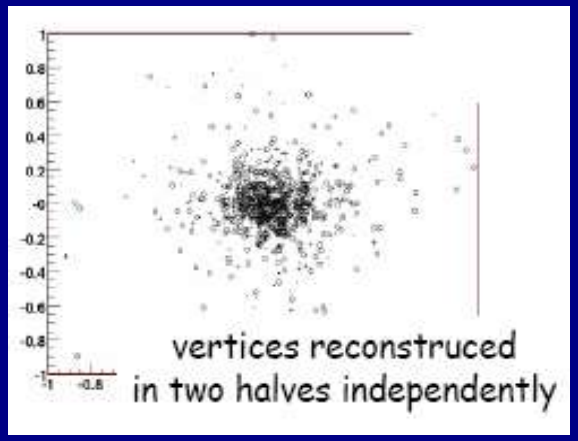
--> expected to be ready in March

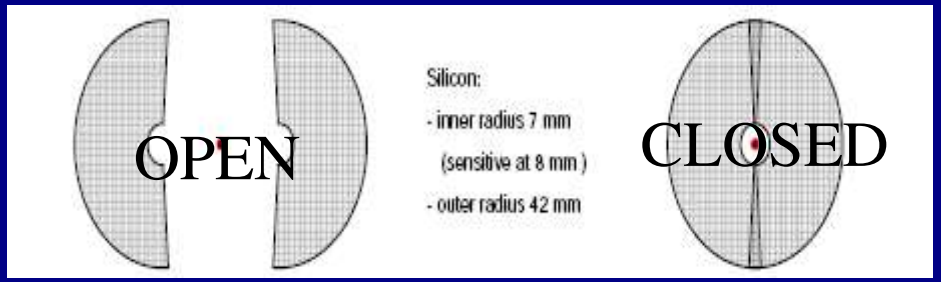


VErtex LOcator: Beam Monitoring

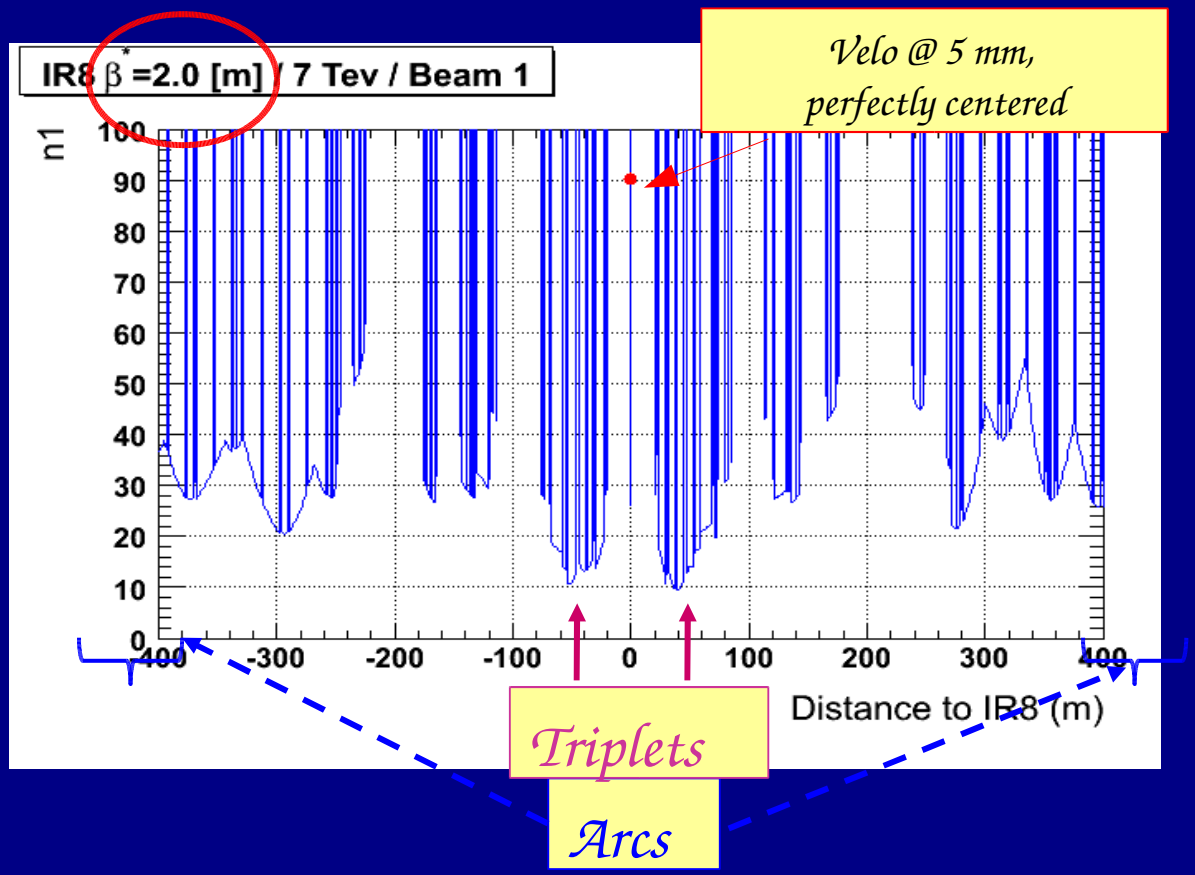
- VELO is a moving detector:
  - it is retracted 30 mm each side at the start of every filling and re-positioned at its nominal position with an accuracy of 10 μm when beams are declared stable
- VELO can track also in OPEN position:
  → interaction point can be reconstructed with 100 μm x,y (15 μm in closed position)







VErtex LOcator: Beam Monitoring



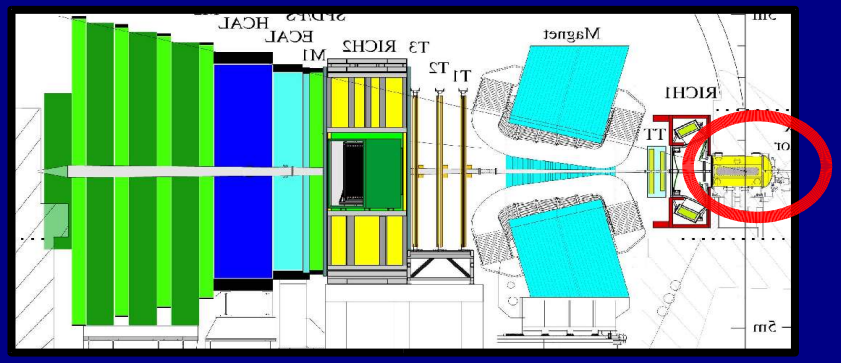
At 5 mm from the beam, VELO remains behind the triplet aperture.

For global perturbations of beam parameters (sigma, orbit) the VELO is always in the shadow of machine elements (Arcs, triples)

VELO is not directly affected by most global LHC failures

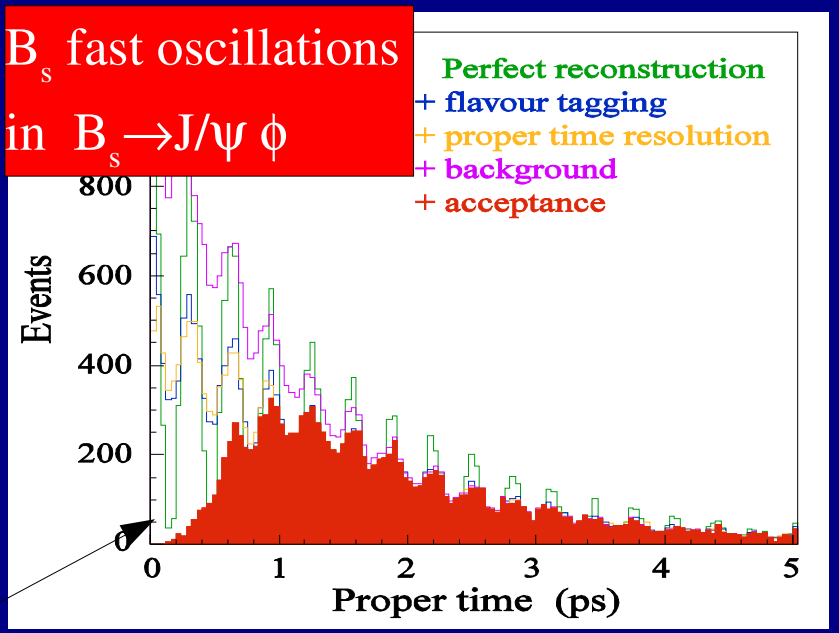
.. anyhow a complex interlock system is indispensable for safe operation of VELO
(interplay LV,HV, cooling,vacuum, beam monitor, motion..)

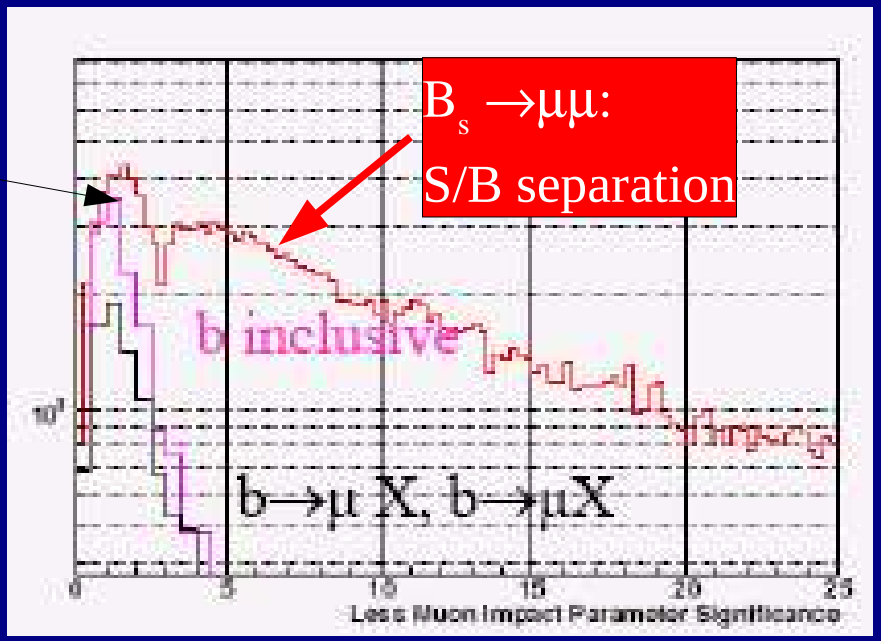
VErtex LOcator: physics issues



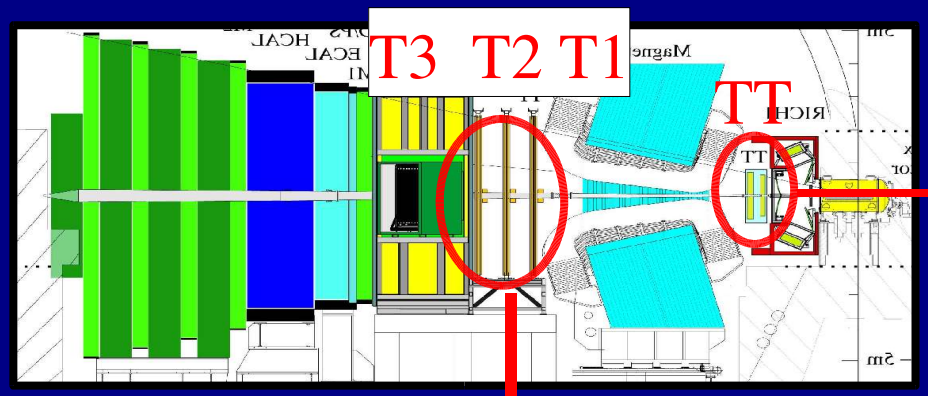
♦ One of the most important detectors for b-physics:

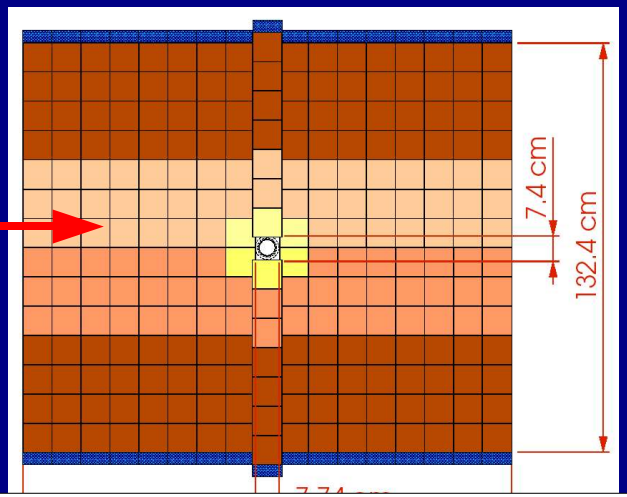
1) primary/secondary vertices reconstruction
   - resolve Bs fast oscillations
   - separate signal from background
2) trigger
   - b decay selection
   - suppression of multiple interactions
3) absolute luminosity measurement





Tracking System: Overview

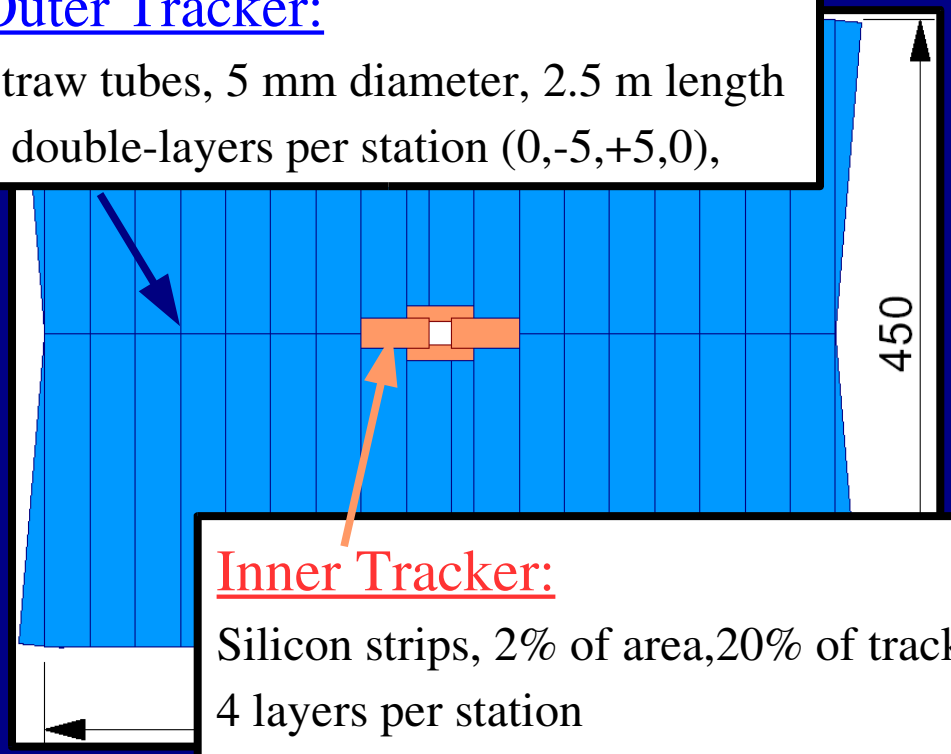




Outer Tracker:

Straw tubes, 5 mm diameter, 2.5 m length

4 double-layers per station (0,-5,+5,0),



Inner Tracker:

Silicon strips, 2% of area,20% of tracks

4 layers per station

TT: ex-Trigger Tracker

now Tracker Turincensis

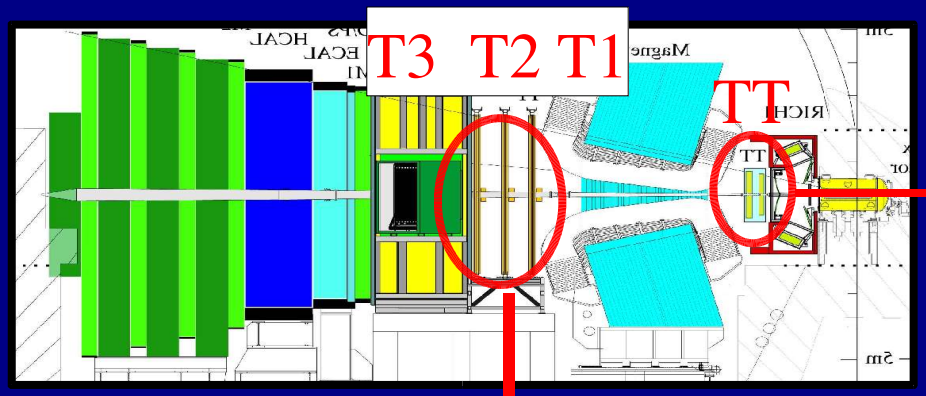
(i.e. from Zurich)

4 layers of Silicon strips,

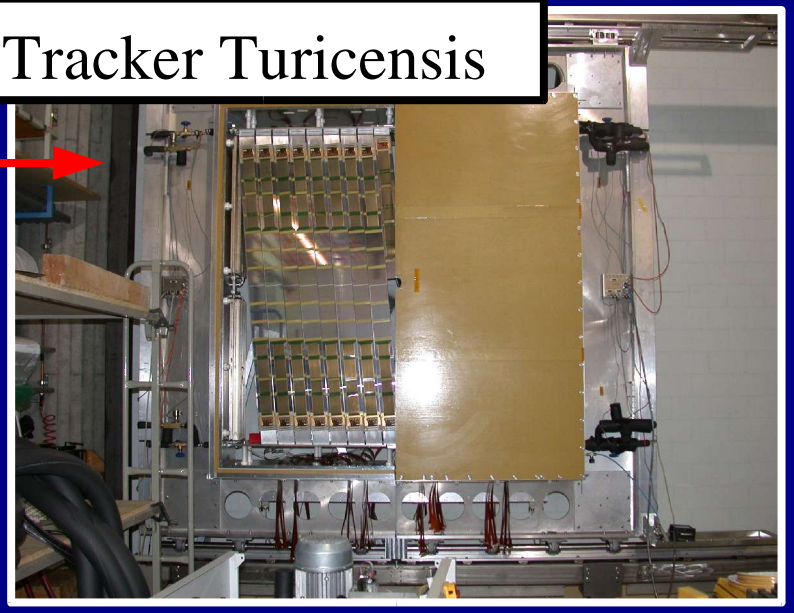
Nominal performance:

- dp/p = 0.35% - 0.55% for p = 1- 150 GeV/c
- tracking efficiency > 95% for p> 5 GeV/c
- $\sigma(M_B)$ ~ 20 MeV/c^2

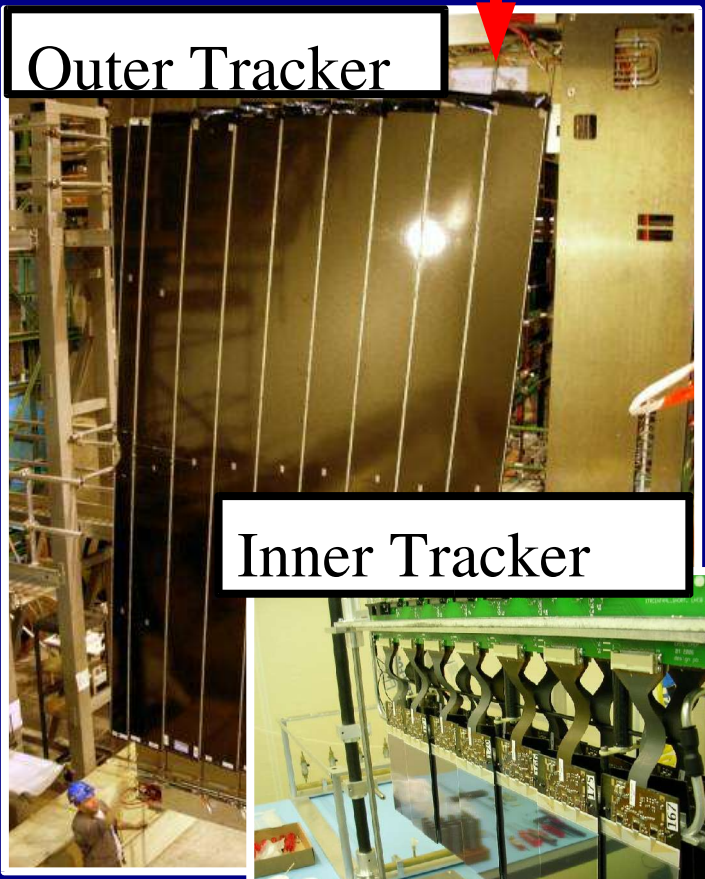
Tracking System: Status



Tracker Turicensis



Outer Tracker

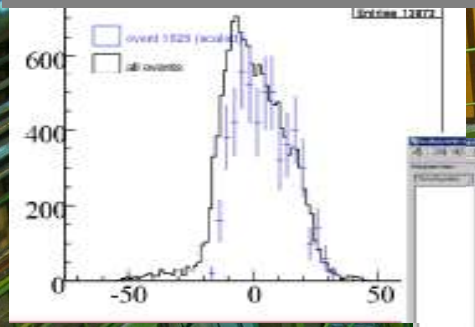


Inner Tracker

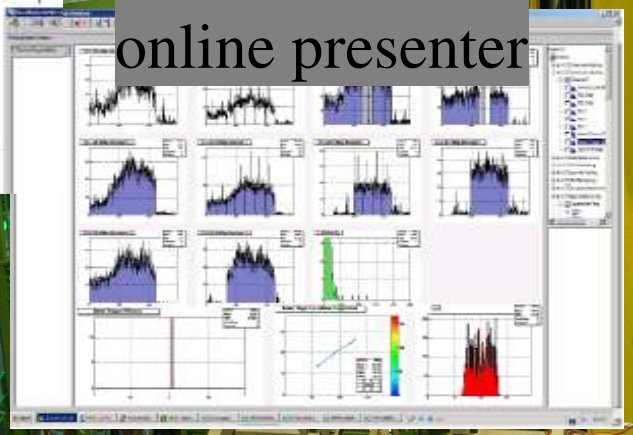
- Outer Tracker:
  → installed, being commissioned
- Inner Tracker:
  → 2 out of 12 detector boxes
  and 2/3 of readout electronics installed
- Tracker Turicensis :
  → installation starts this week

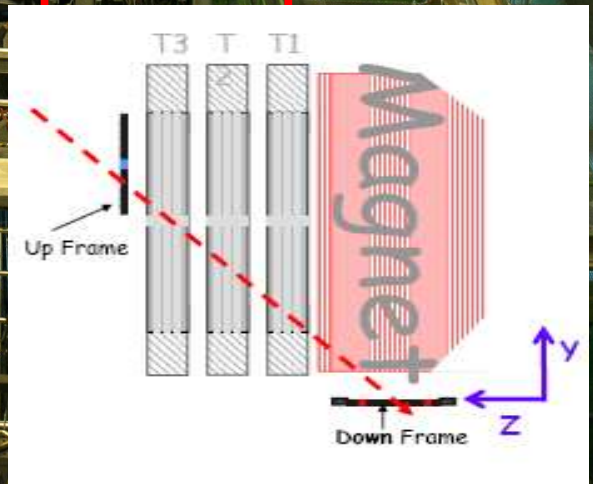
Cosmics in Outer Tracker

drift time distribution



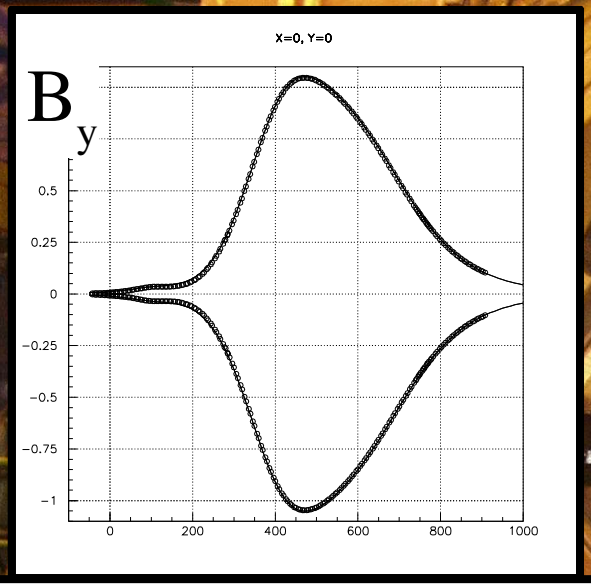
online presenter



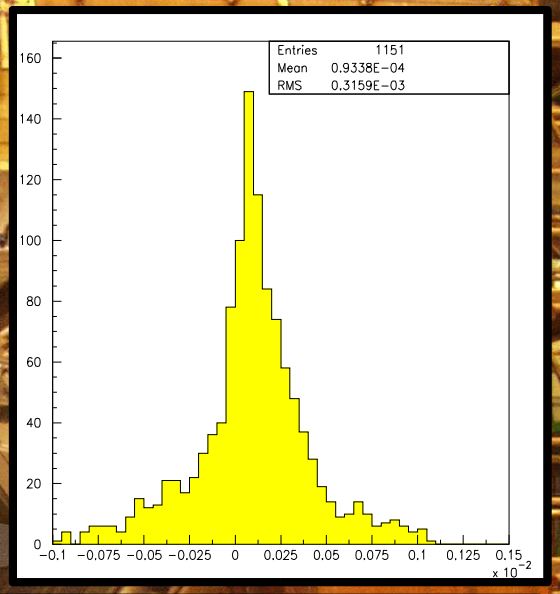


- Cosmics in LHCb: (100 m underground) ~1 Hz/m^2
- Trigger: coincidence of two scintillators planes at ~45°
- Rate: 25 mHz of cosmics ~ 2100 events/day
- Status: T3 is acquiring data, T1-T2 will follow asap.

Magnet



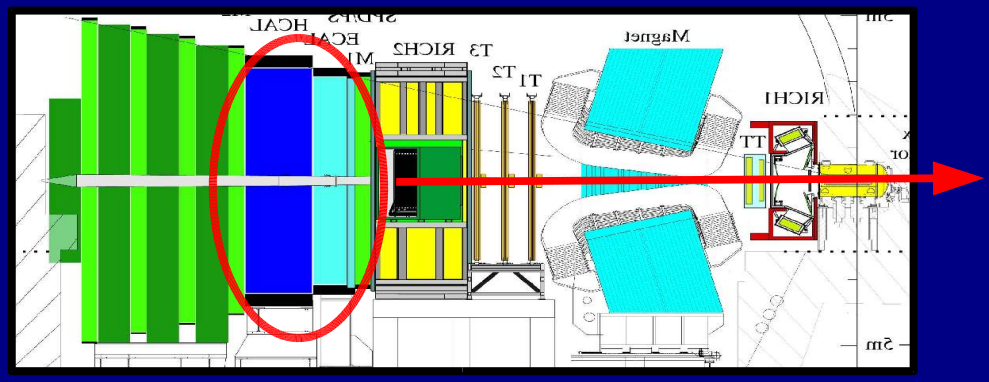
Peak field on axis: 1.1 T
Field integral: 4 Tm (over 10 m)



Final map for both polarities measured in 2005:
→ B known at < 0.03% level

Magnet has been switched on and commissioned in October 2007 with the three compensator magnets under LHC control

Calorimeters



STRUCTURE:

Four sub-detectors:

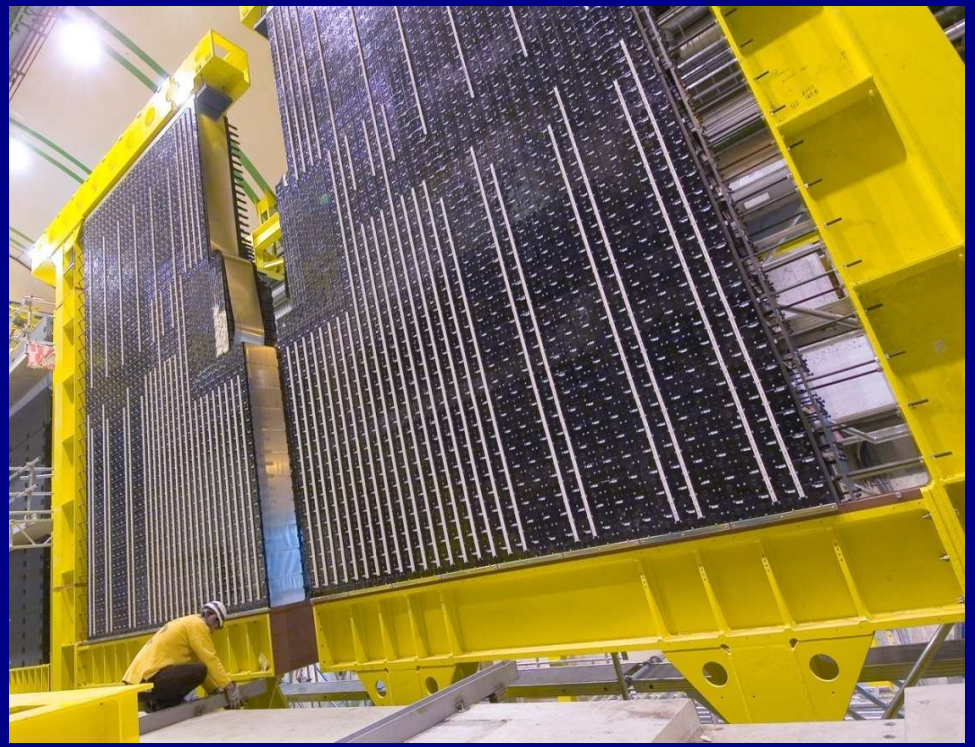
- SPD/PRS (Pb/Scintillator)
- ECAL: Pb/Scintillator shashlik
- HCAL: Fe/Scintillator tiles

STATUS:

♦ All modules have been installed

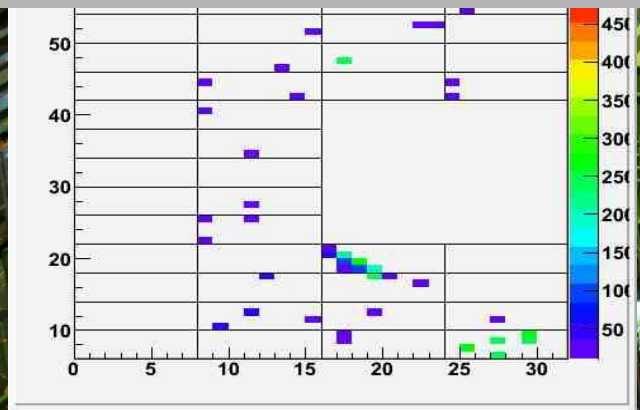
♦ Half of the system is operational and is being commissioned now

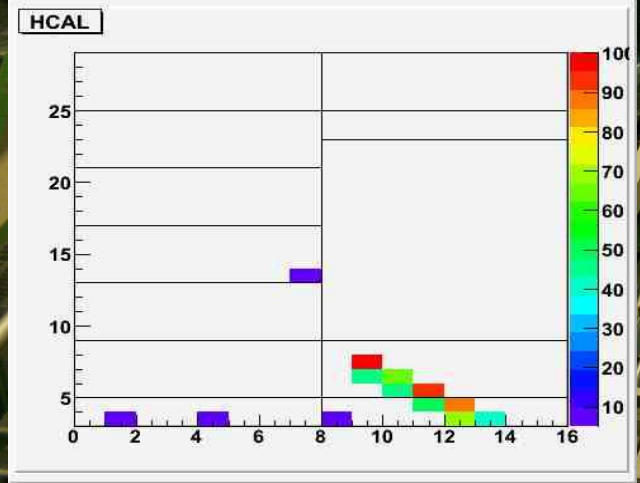
♦ Second half of the system is being completed, expected to be fully operational end of March.



Cosmics in Calorimeters

cosmics in ECAL+HCAL





♦ ECAL/HCAL internally time aligned with 1 ns accuracy using LED pulses

♦ Commissioning phase started with cosmics:

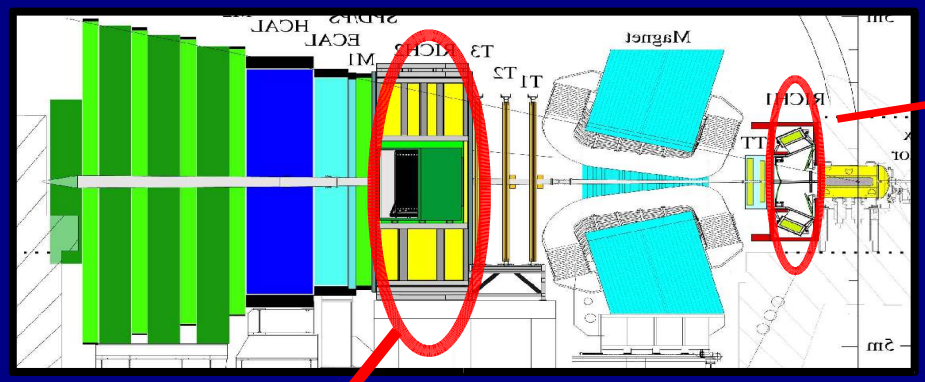
- 5 Hz of cosmics in acceptance
- L0 calorimeter trigger running with ECAL+HCAL coincidence

♦ Successful test of full chain:

calo →trigger→DAQ→ Data on disk→ Decoding

RICH

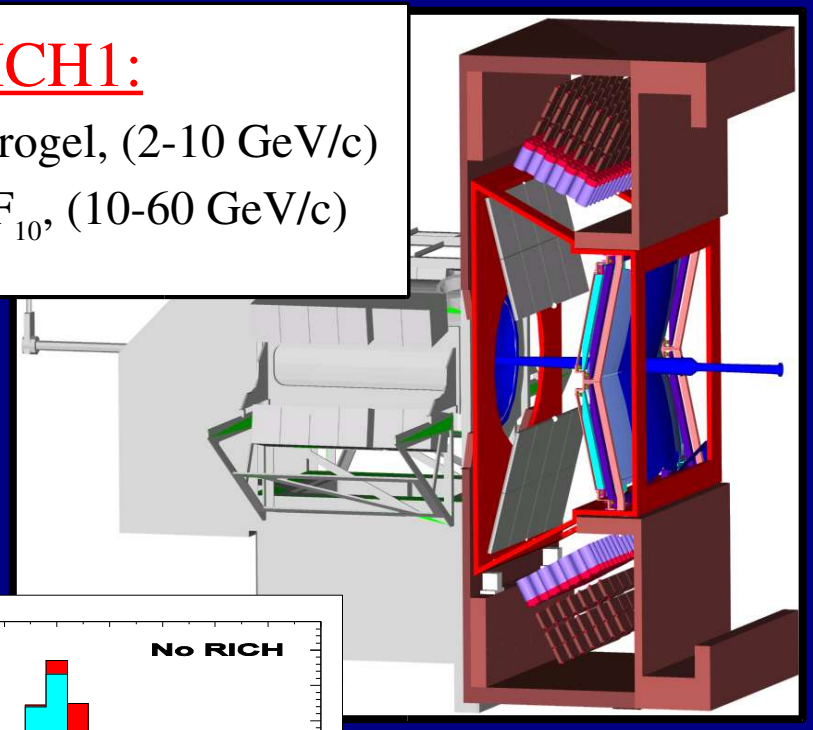
Kaon-pion separation provided by two RICH detectors in 1-100 GeV/c range



RICH1:

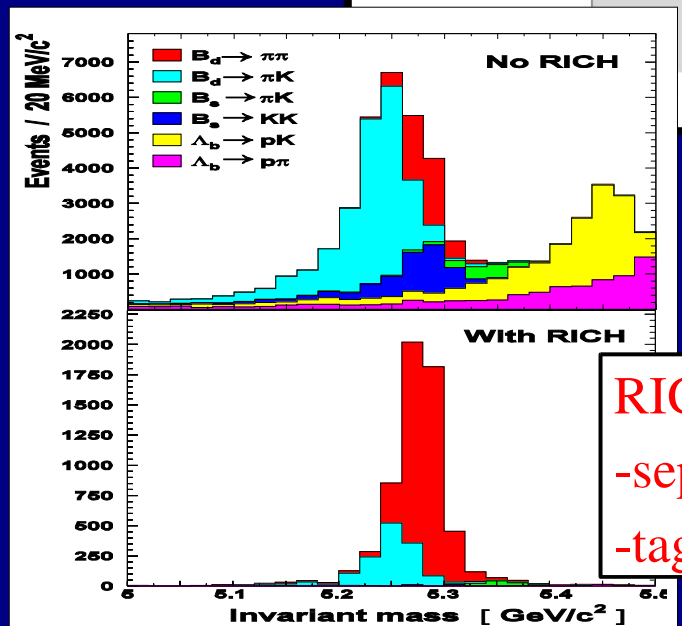
Aerogel, (2-10 GeV/c)

C_4F_{10}, (10-60 GeV/c)



RICH2:

CF_4 (16-100) GeV/c



RICH system is critical for:

-separation of B→hh modes

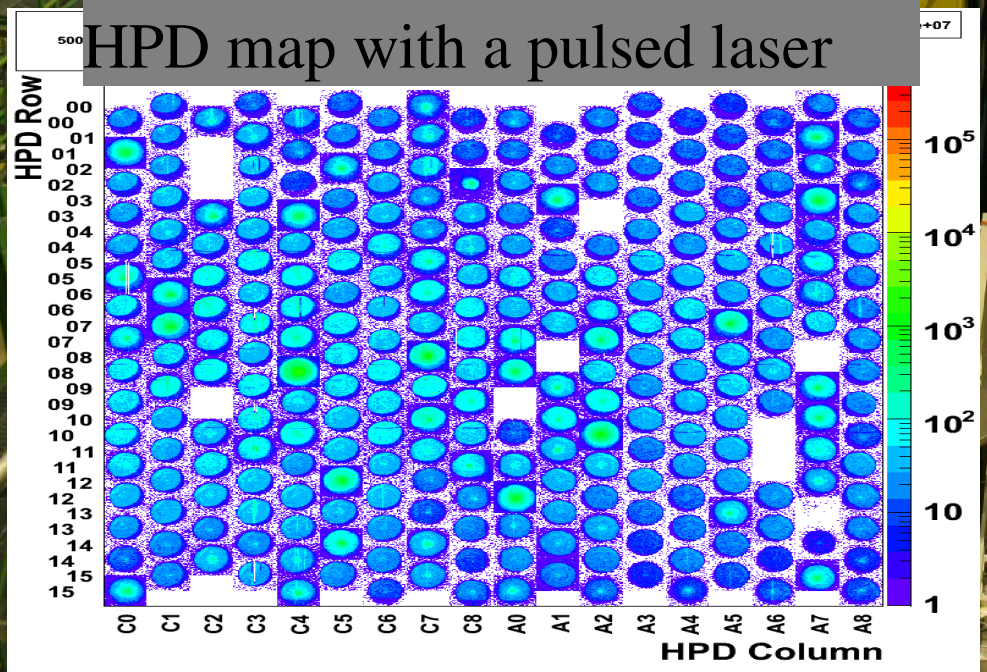
-tagging

Status of the RICH system

RICH2

It has been succesfully operating since few months and has being commissioned with a pulsed laser

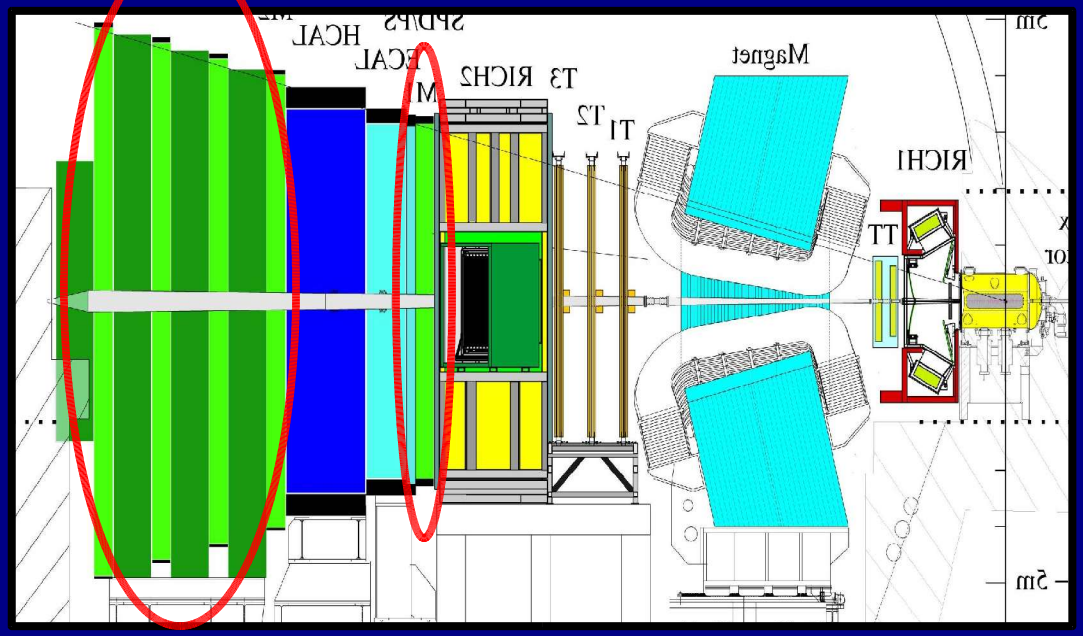
HPD map with a pulsed laser

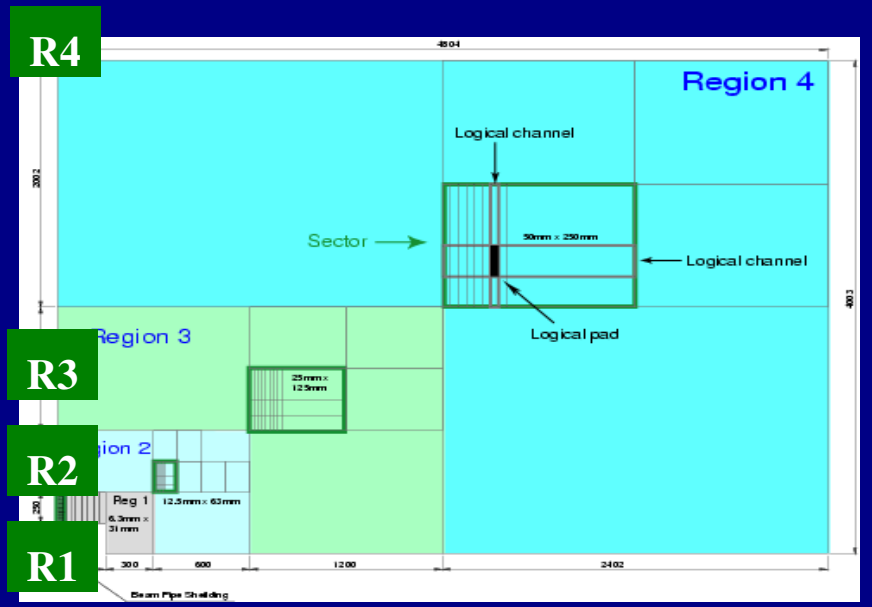


RICH1:

- Gas enclosure and all mirrors installed,
- All HPD delivered and tested
- HPD upper box is being installed, lower one within March
- Photon funnel and magnetic monitoring system are late but expected to be ready end of April

Muon Detector

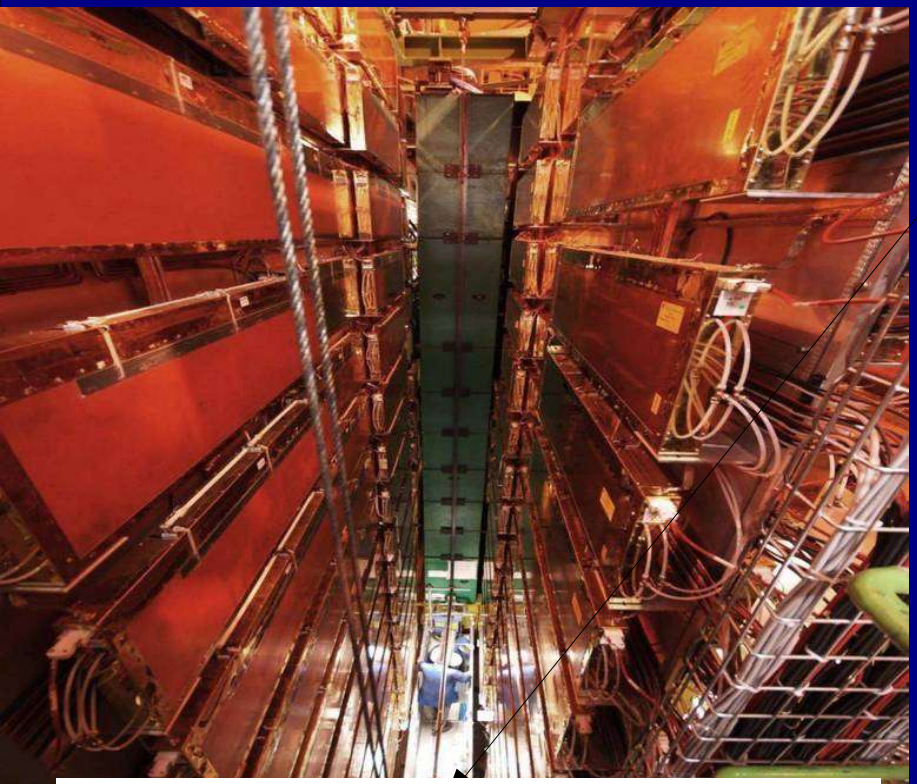




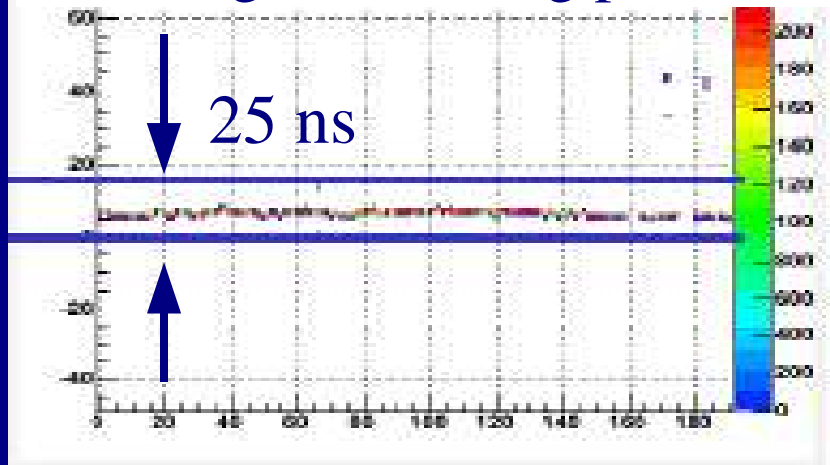
- 5 Muon Stations, one in front (M1) and four after (M2-M5) the calorimeters
- 435 m^2 area, equipped with 1380 MWPC (99.9%) and GEM (0.1%).
- Key detector for LHCb:
  - → Must provide the L0 muon trigger (5 hits in 5 stations in 25 ns time window).
  - → 1500 Hz out of 2000 Hz output rate of HLT comes from muon channels
  - → three key channels in LHCb have muons:

    $Bs \rightarrow \mu\mu$, $Bs \rightarrow J/\psi\ \phi$, $Bd \rightarrow K^*\ \mu\mu$

Muon Detector



Time alignment using pulses



♦ **M2-M5:** 98% of chambers installed.

♦ One quadrant has been time aligned using pulse system:

- DAQ running on a single dedicated farm node
- Successful test of the whole chain:

pulse → L0 muon trigger → FEE → DAQ → Data on disk → decoding

♦ Gas and HV ready to be put in.

♦ Stand-alone cosmic trigger setup and ready to be used (expected rate: 5-10 Hz)

--> expected to be operation from February on

Where we are now:

Sub-Detectors:

- Outer Tracker, Calorimeters and RICH2 are delivering data
- L0 is being commissioned using cosmics (Calorimeters) and pulse system (Muon)
- Muon system (M2-M5) and VELO expected to deliver data very soon
- RICH1, Inner Tracker and TT partially installed, but foreseen to be ready for end of April.

Global Commissioning:

- Use cosmics as much as we can for acquiring as much sub-detectors as possible (as soon as they are ready) with a common trigger provided by ECAL+HCAL or Muon:
  - → Time align the sub-detectors all together
  - → Identify problems as soon as possible

Scheduled 4 weeks of Global Commissioning in the next three months....

What do we need next?

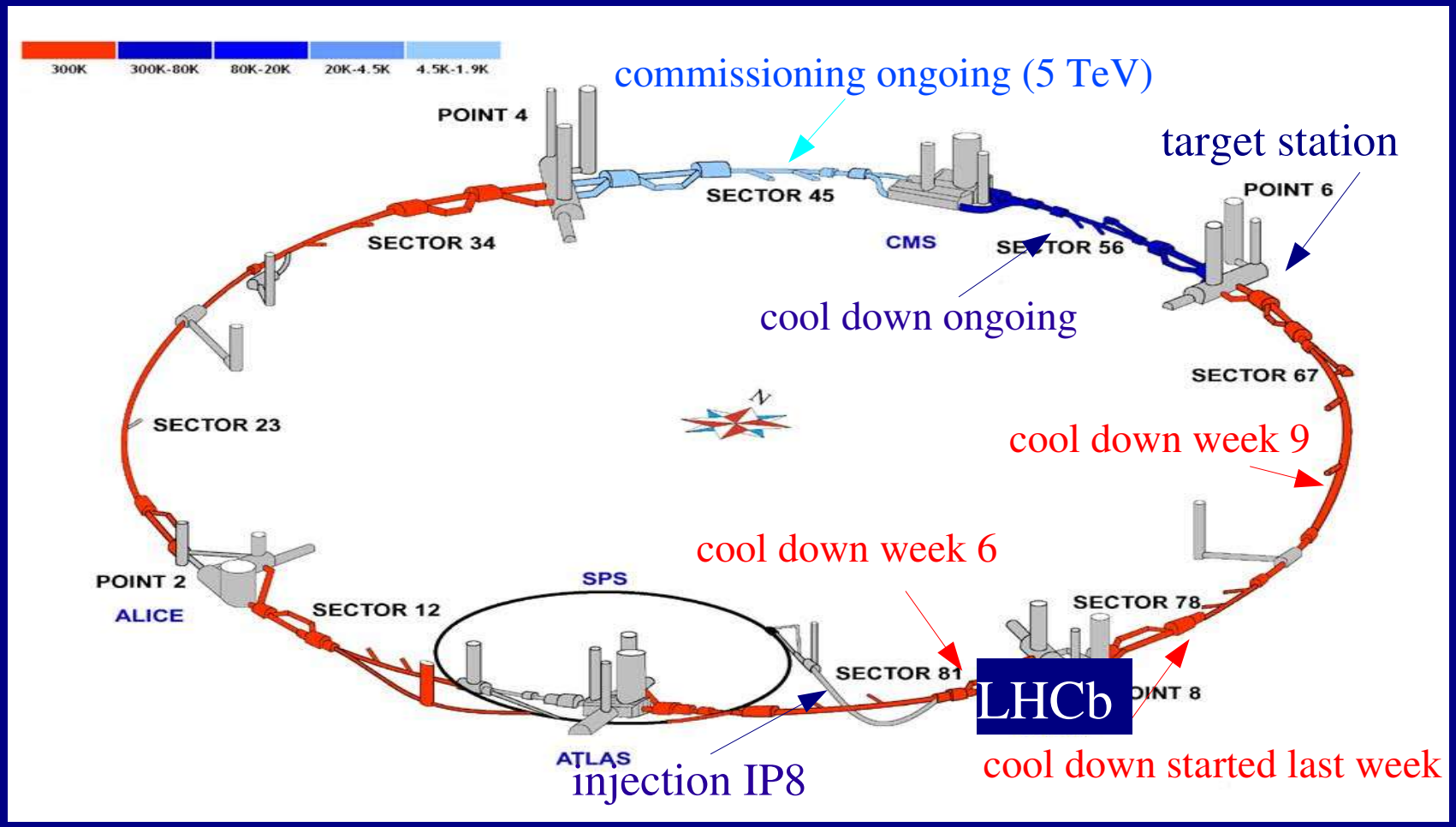
- Some interactions from the machine:
  → even beam-gas interactions or beam halo during machine commissioning are useful to start with.
- A very preliminary and rough trigger to start the acquisition:
  → given by HCAL

→ With this trigger:
- synchronize all the sub-detectors to acquire the same bunch crossing
- switch ON the Level 0 trigger.

→ With the Level-0 trigger:
- align in space the tracking system in order to see some tracks

→ With tracks we start the real job:
- Switch ON the HLT
- Momentum and Particle ID calibration
- very very early physics measurements

Status of LHC machine



In the present situation:

- machine cold end of June
- first beam injection beginning of July

Impact for LHCb:

- sector test may/will come
- UX85 will be closed in April....(!!!)

LHC running conditions in the very early stage from LHCb point of view

(R. Bailey, LHCb week, September 2007)

- Pilot Beam ("probe beam", 450 GeV):
  - single bunch, 5 to10x10^9 protons
- Pilot^{++} ("measurement beam": higher intensity, 450 GeV)
  - single bunch 3 to 4 x 10^{10} protons
  - 4, 12 bunches etc, pushing towards 43, 156 bunches, 3 to 4 x 10^{10} ppb
- Shifted bunches for LHCb:
  - 4 out 43, or 24 bunches out of 156
- Crossing angle off:
  - head-on collisions in the configuration of 1,12,43, 156 bunches per beam
- LHCb magnet OFF (to start with..)
- VELO in OPEN position

Commissioning with beam: beam-gas and halo

- Use beam-gas interactions and beam halo:
  - give useful tracks for time and space alignment ...
    .... if we will have the beam in the right direction:

hadron halo:

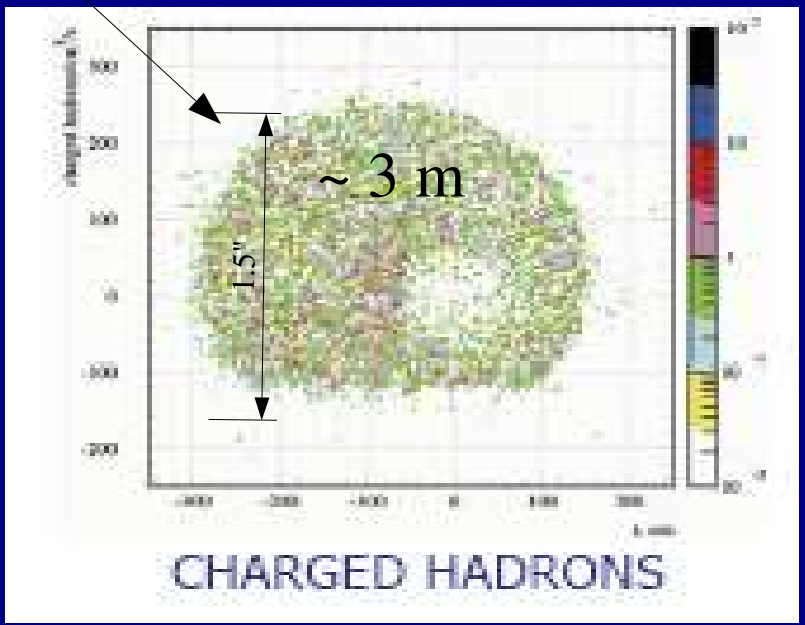
$10 \rightarrow 10^{-1}$ hadrons/cm^2/s
depending on shielding

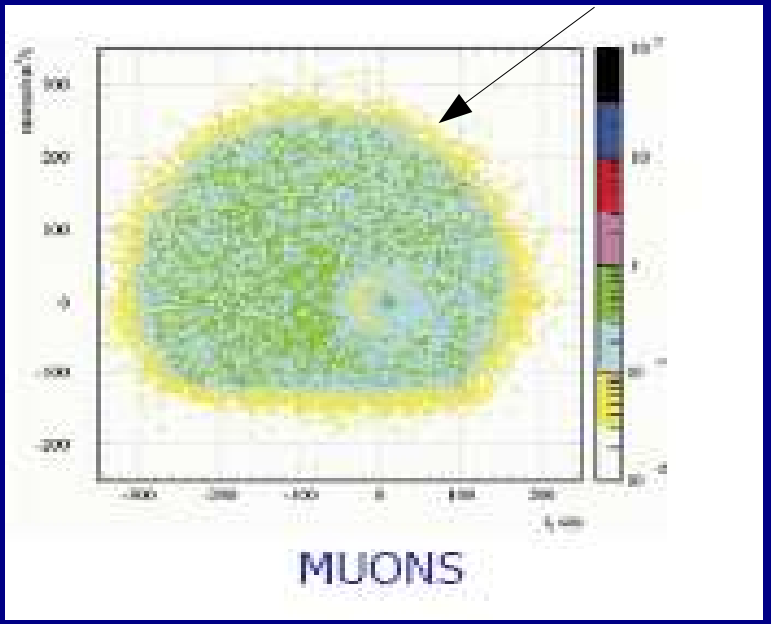
beam gas

4 mHz per bunch
(~160 mHz per 43 bunches)

muon halo:

$10^{-1} \rightarrow 1$ muon /cm^2/s
depending on shielding





Commissioning with beam: Minimum Bias

Luminosity	Nr bunches	pp-int/xring	non-empty rate	L0-YES
1.1×10^{29}	4	0.15	6 kHz	3 kHz
2.3×10^{30}	16	0.76	94 kHz	47 kHz
2.6×10^{31}	936 (75ns)	0.15	1.4 MHz	0.7 MHz
2.0×10^{32}	2622 (25 ns)	0.4	10 MHz	1 MHz

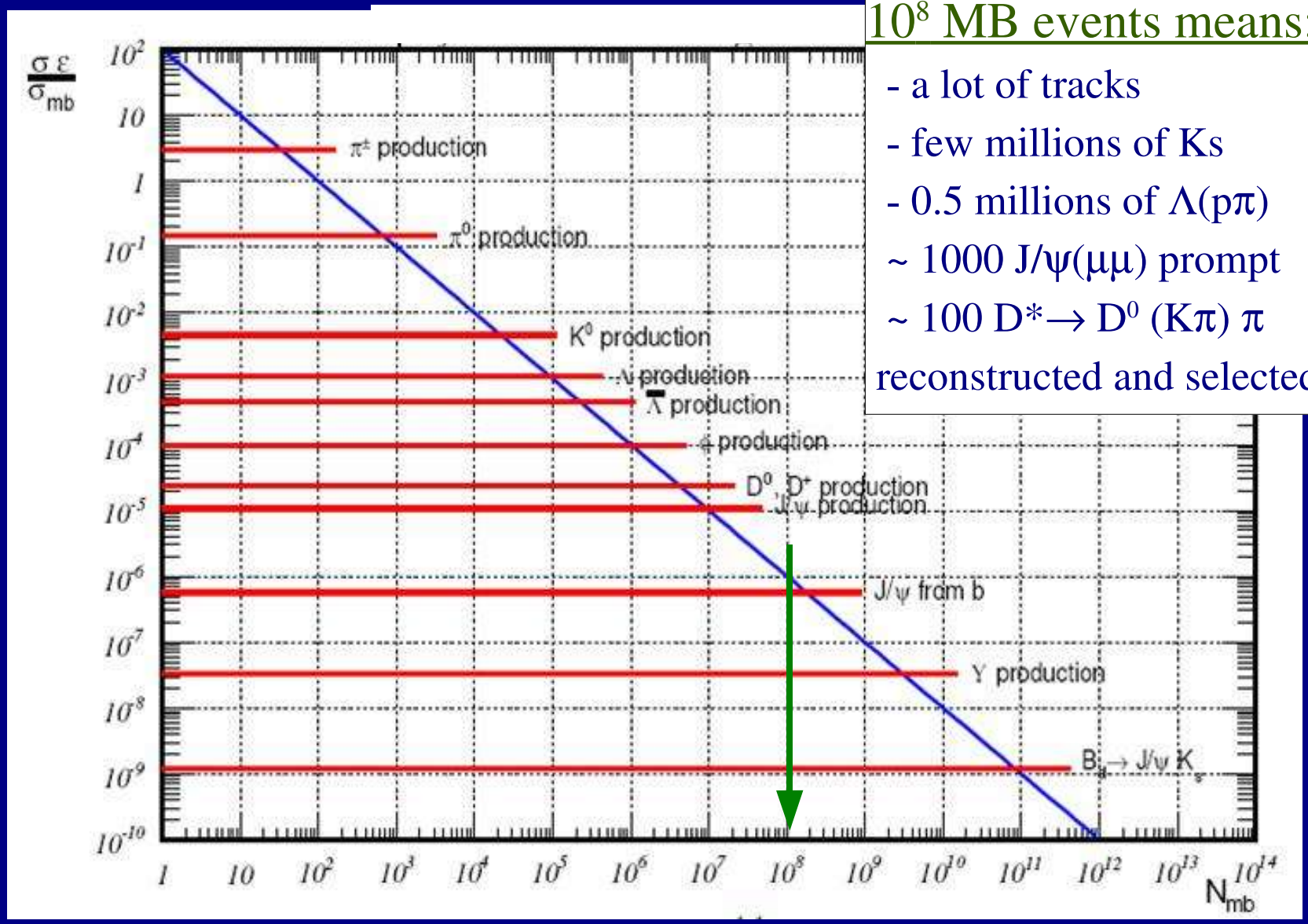
Pessimistic/realistic scenario:

- Only 4 filled bunches at $L=1.1 \times 10^{29}\ cm^{-2}\ s^{-1}$
- L0 thresholds lowered to achieve a factor x2 reduction on MB events
- 300 Hz of non empty minimum bias events to disk

$\rightarrow 10^8$ MB events in ~100 hours of running

- Computing infrastructure for quasi-online reconstruction and analysis of 10^8 events available (0.5% of the nominal annual data volume)

Particles available as a function of Minimum Bias collected



10^{8} MB events means:

- a lot of tracks
- few millions of Ks
- 0.5 millions of $\Lambda(p\pi)$

~ 1000 $J/\psi(\mu\mu)$ prompt

~ 100 $D^{*} \rightarrow D^{0}\,(K\pi)\,\pi$

reconstructed and selected

Global Time alignment

- Time synchronization of LHCb as a whole requires particles traversing it synchronized with LHC clock.
  - start using beam-gas interactions and continue with collisions.

- Use HCAL trigger as interaction trigger synchronized with LHC clock:
  - synchronization with the machine clock done by looking at E vs time.
  - no threshold: simply collect all the events.

- Read out all detectors together:
  - Special DAQ mode (multi bunches readout) to record events in an enlarged gate
  - Each sub-detector can measure its time with respect to the trigger time and determine the best settings of programmable delays.

→ Just a global parameter for each sub-detector:

→ some thousands of tracks are enough.

→ Once the sub detectors are aligned:

→ switch to the normal DAQ single bunch readout.

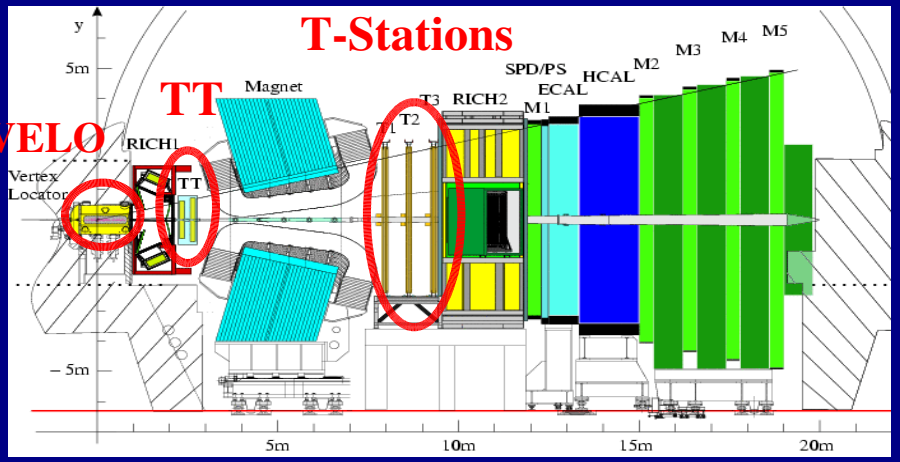
Space alignment of Tracking Detectors

- Start aligning the tracking detectors:
  - hardware surveyed to different precision:
    → tracking system at 0.3-0.5 mm

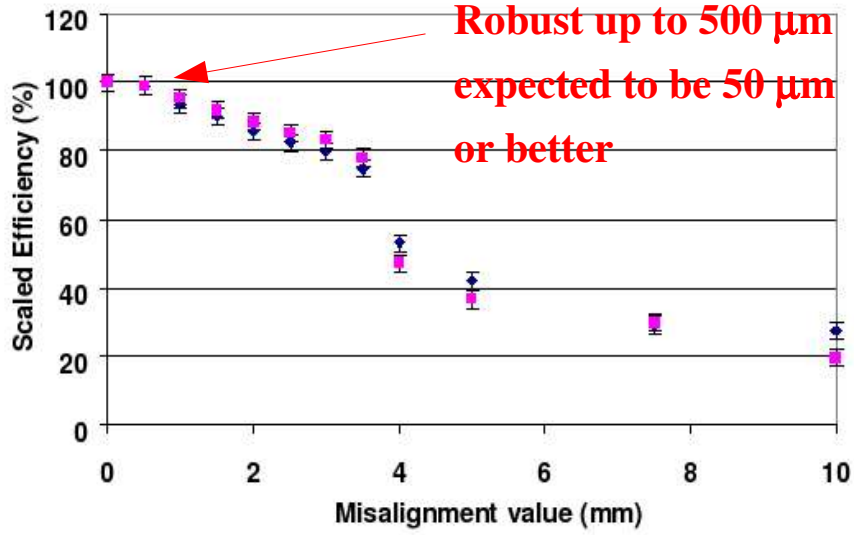
- Magnet OFF data:
  to separate magnetic field effects from geometrical ones:
  → use energy in calorimeters to select high p tracks.

- First align VELO and T-Stations independently from each other, then TT versus VELO & T-Stations:
  → several 10k clean, high p tracks.

- Magnet ON data:
  → global degrees of freedom of each detector plane



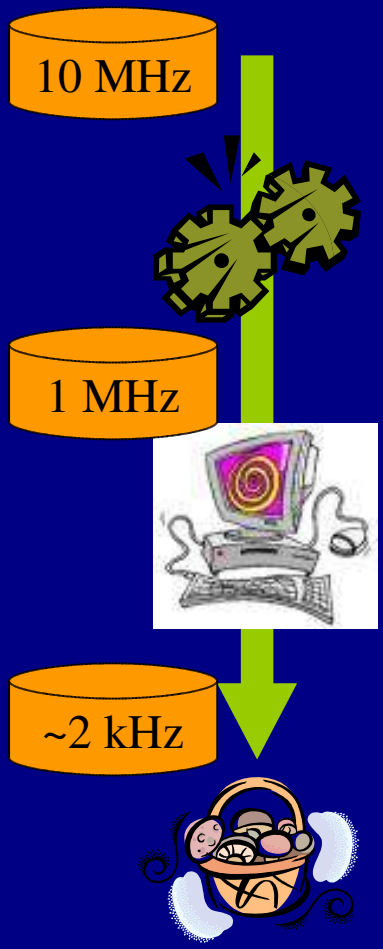
Effect of OT misalignment on tracking efficiency



Switch On the Trigger

Nominal conditions:

Conditions at the start-up:



Luminosity:

$L = 2\ 10^{32}\ cm^{-2}\ s^{-1}$ → $L \sim 10^{29}\ cm^{-2}\ s^{-1}$ (4 bunches) ramping up

L0: [hardware]

high Pt particles → L0 will be ready very soon even if not fully efficient

calorimeter + muons

Pt/Et threshold will be chosen as a function of L

HLT [software]

1 MHz readout → Online Farm Status:

~1800 nodes farm

12 nodes availabe now, 200 expected for June

> 1000 nodes for the end of the year

On tape:

200 Hz Exclusive selections

1800 Hz Inclusive streams

HLT: switched on in transparent mode

(i.e no trigger applied) as soon as we have tracks

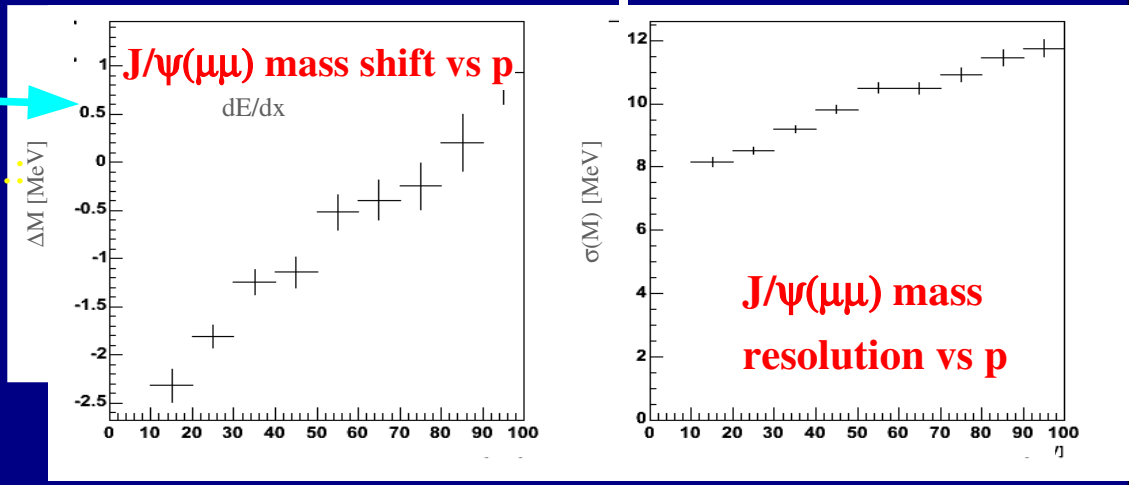
--> priority given to inclusive modes

Calibrations, calibrations. calibrations:

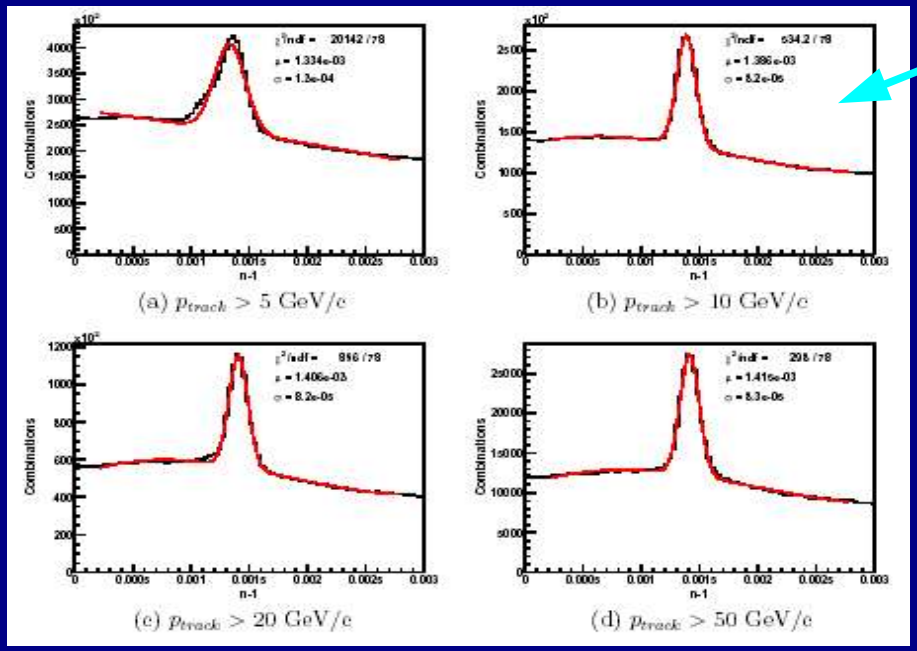
Momentum resolution and scale:

use J/ψ , Ks, masses as a function of p, pt, etc…

- mass shift and mass resolution sensitive to momentum scale calibration and momentum resolution



Calibration of refractive index in RICH:



- Variations in gas refractive index will be generated by pressure changes :

$\delta P = 10$ mbar $\rightarrow$ $\delta(n-1)/(n-1) \sim 1\%$

$\rightarrow \Delta\theta c = 0.27/0.16$ mrad in RICH1/RICH2 which is similar to ring resolutions

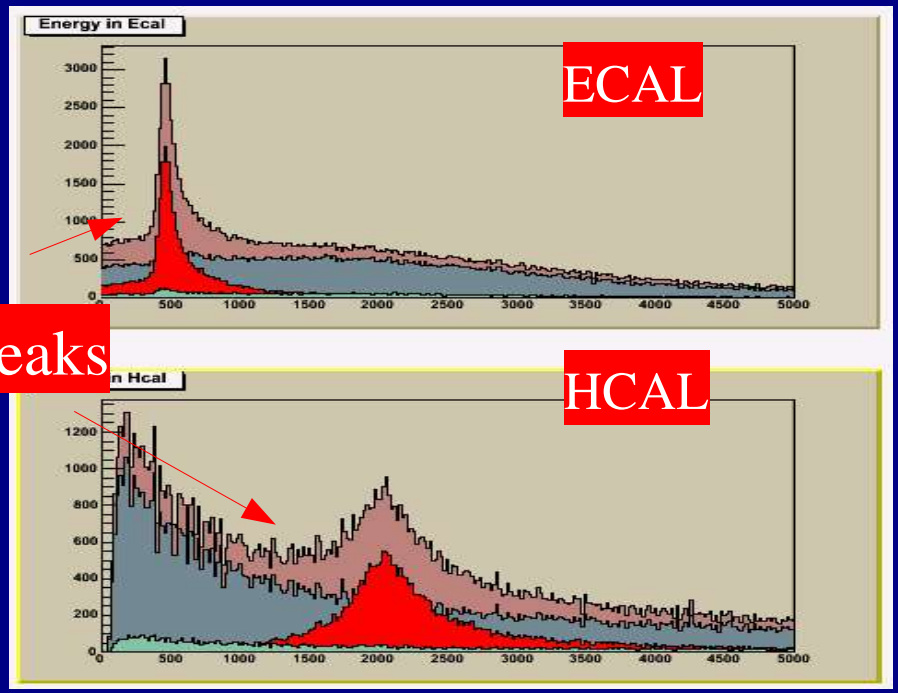
- Refractive index can be monitored and calibrated by looking at high momentum tracks and assuming $\cos\theta = 1/n$

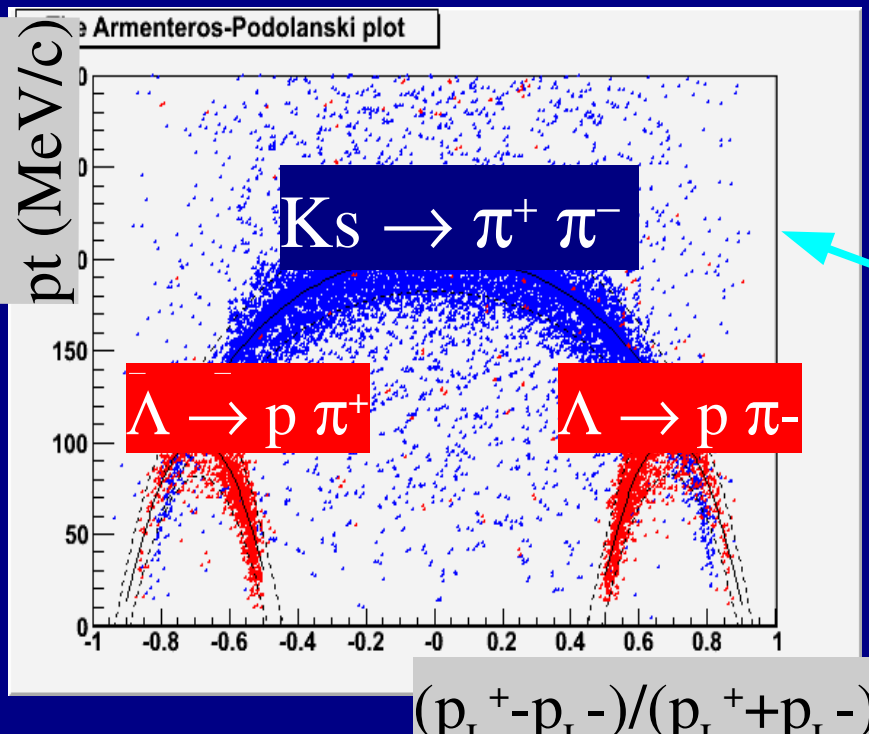
Calibrations, calibrations. calibrations...

MuonID Calibration:

Map ECAL&HCAL MIP peaks

Use MIP to select muons to calibrate the muonID





RICH ID Calibration:

Select protons and pions from prompt Ks/Λ decays using kinematics

- Use them to calibrate RICH-PID (proton-pion)
- Use the D*→D0 (π K) π chain for K-π separation only when L increases

Summary

- LHCb is being installed and partially commissioned with cosmics
  → hope to have the detector ready for end of April

- Time and space alignment of the detector will be the first issues to be addressed with the beam:
  → problem will not be the statistics
  → few samples of ~10k of events will be enough

- L0 will be operating with a lowered threshold (tunable with L).

- The HLT will run in transparent mode as soon as the tracking works
  - Priority will be given to inclusive streams, in particular muon streams

- PID calibrations will go in parallel as soon as the tracking works.

We are working hard.....


gas system in muon chambers


cabling the calorimeters


LHCb control room


Survey & alignment of Outer Tracker:


Testing VELO connections:

... to be in good shape for the first data....

SPARES

L0 Trigger:

L0-Calo:

Hadron, Ecal (pi0,e, gamma):

- highest Et candidate above Et threshold
- Global variables:
  - -total Energy
  - - SPD multeplicity

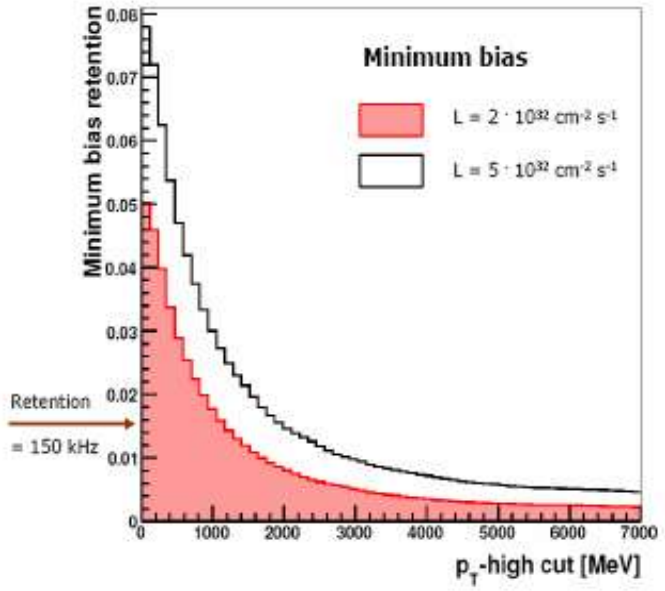
L0-Muon:

2 highest pt muons per quadrant:

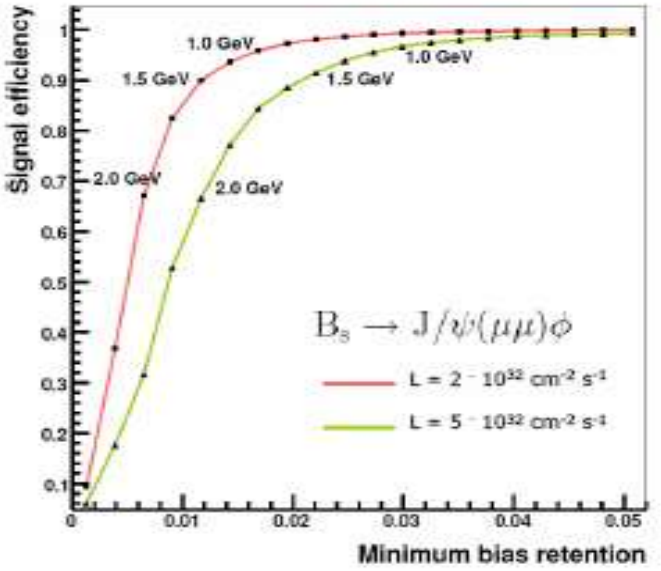
- 1 muon with pt> ptmin (1.1 GeV)
- 2 muons with ptsum > ptsum (1.3 GeV/c)

Pt/Et Thresholds will be reassessed as a function of L

Minimum Bias retention as a function of pt cut

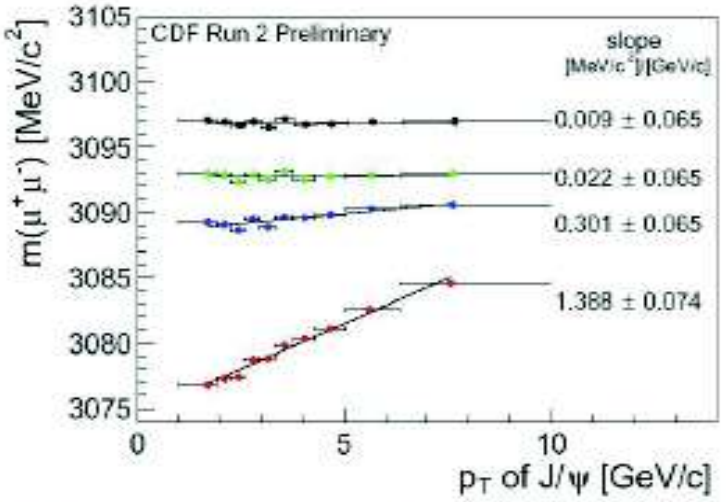


Signal efficiency vs minimum bias retention for different pt cuts:



Momentum calibration : the CDF example

First: use J/ψ(μμ) events → Second: use Ks, D0, Υ to cover the full phase space

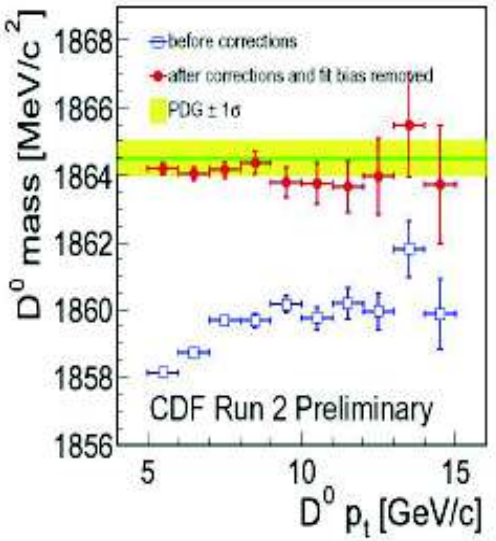


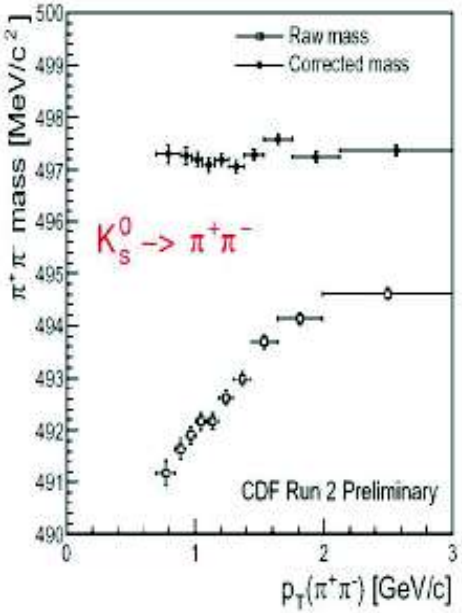
Calibration procedure

+ raw tracks
+ nominal *E* loss corrections
+ fine tuned *E* loss corrections
+ adjust overall scale (*B* field)

Using J/ψ calibration

+ low momentum (π): $K_s \to \pi^+\pi^-$
+ high stat. (K, π): $D^0 \to K^+\pi^-$
+ high momentum (μ): $\Upsilon \to \mu^+\mu^-$





→ we will do exactly the same:

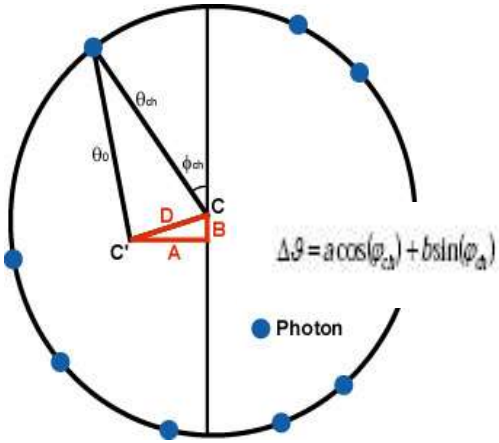
→ J/ψ(μμ) and Ks very easy to be identified in LHCb

RICH alignment

- The two RICH detectors are the most sensitive to misalignment since knowledge of the track vector contributes to the Cherenkov angle resolution:
  - precision of reconstruction of Cherenkov photon angle is expected ~ 1 mrad (RICH1) and ~ 0.5 mrad (RICH2).

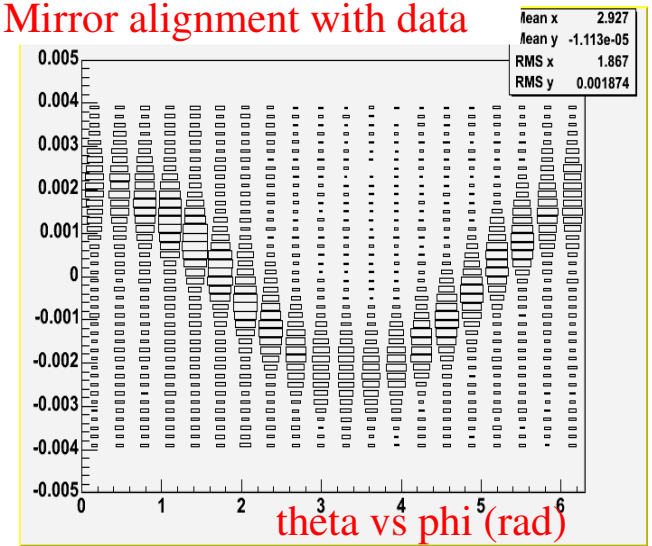
- Survey of all the mirrors with a laser system:
  at < 0.5 mrad precision in RICH1 and ~ 1 mrad in RICH2.

- With data, mirrors are aligned by comparing the reconstructed photon positions with those expected (based on charged track parameters):
  for fixed misalignment the bias per photon varies.



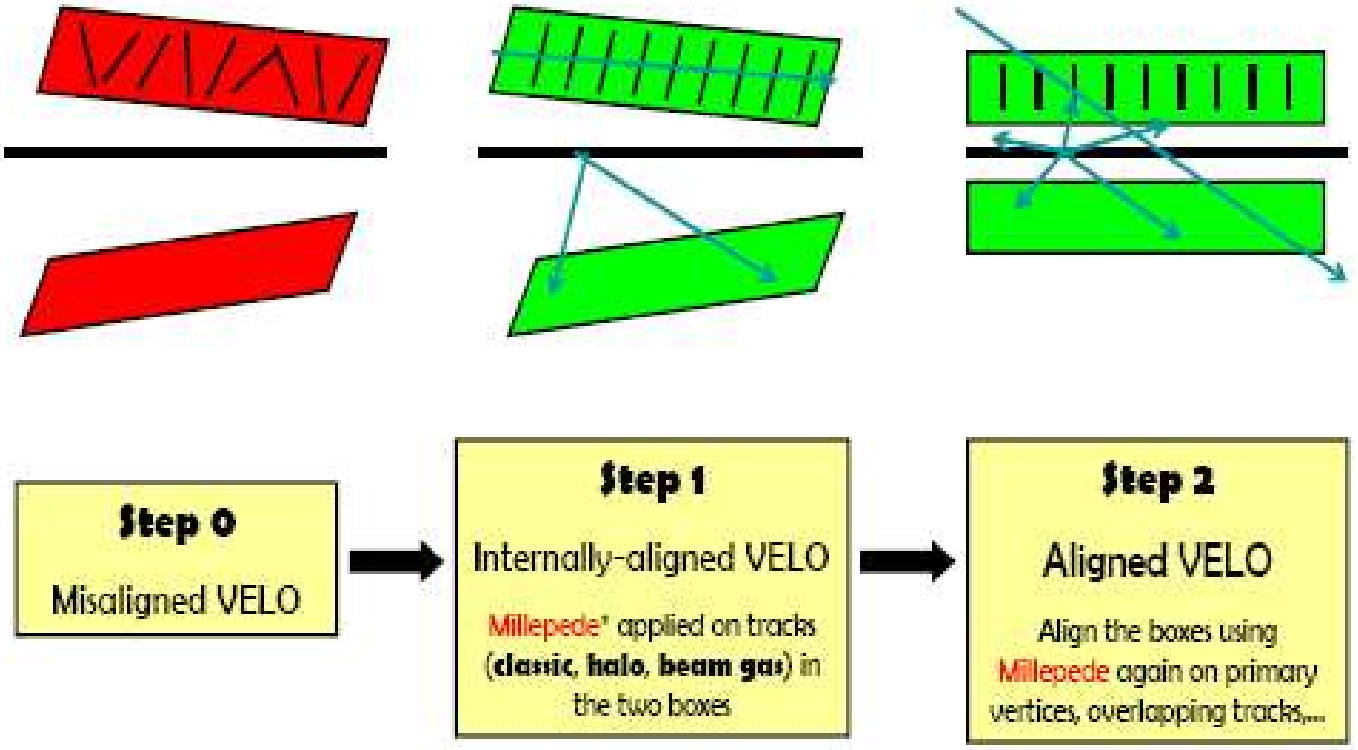
- A plot of theta vs phi can be used to extract misalignment parameters.

Mirror alignment with data



- Saturated tracks (β=1) can be used to predict the Cherenkov angle.

How do we find the VELO alignment parameters?

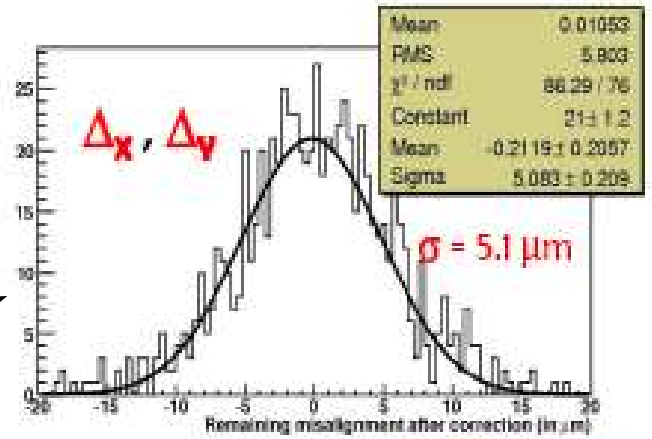


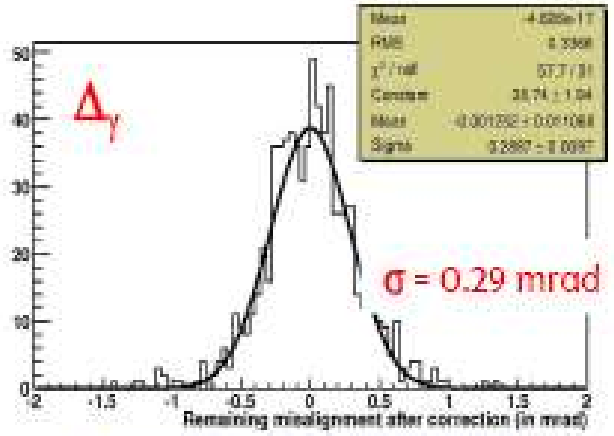
What type of tracks for internal alignment?

Simulation of few thousand MB events and halo tracks

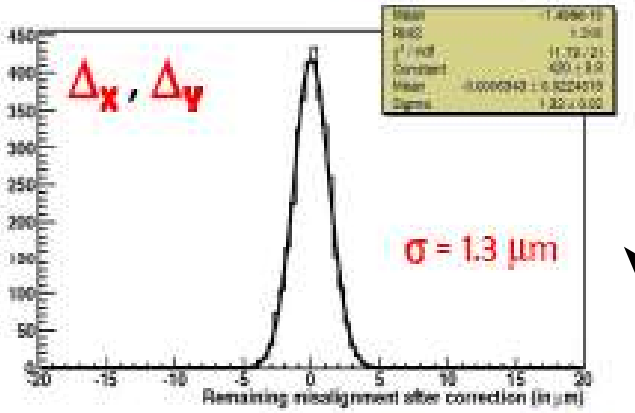
Sebastien Viret

Minimum Bias only

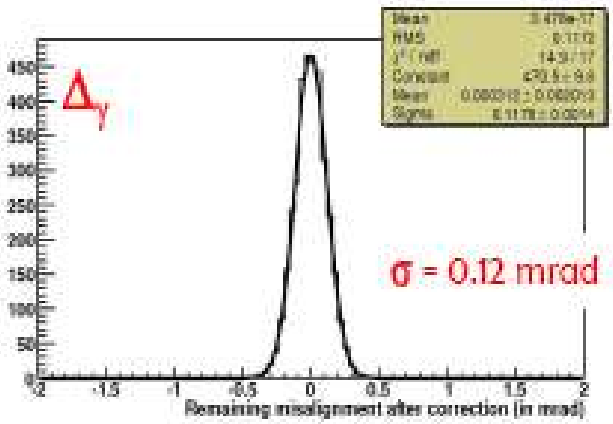




STEP1 with min. bias only



Minimum bias + halo

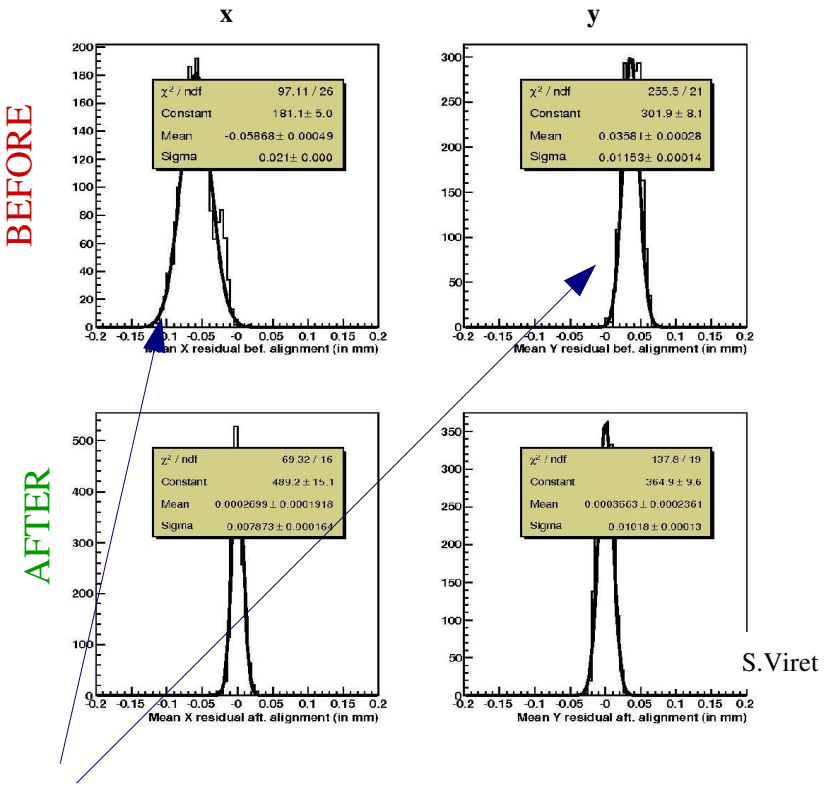


STEP1 with min. bias + halo tracks

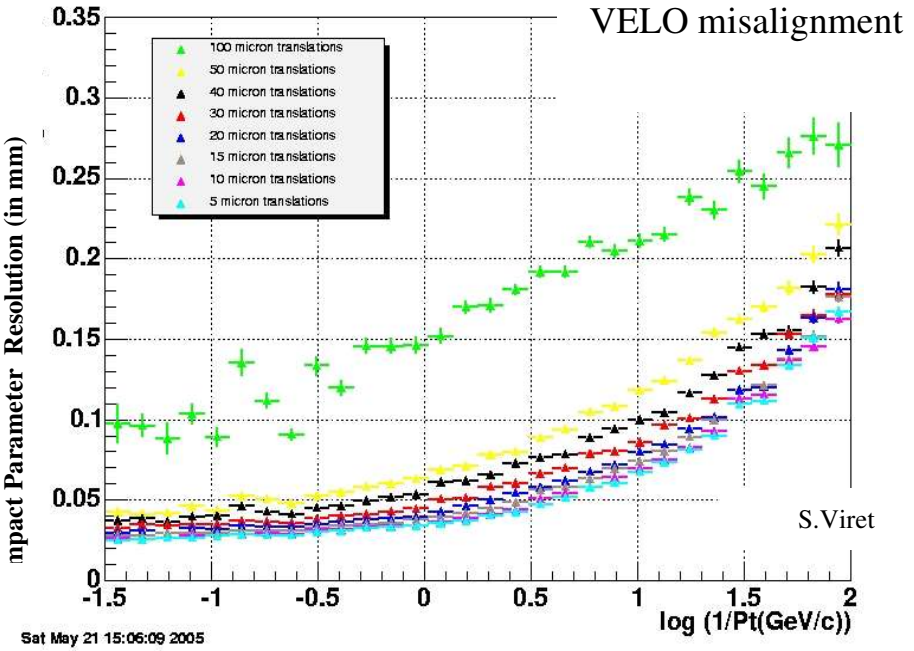
beam-gas tracks can help too (like halo tracks)

Internal alignment with an accuracy of 2 µm using minimum bias+ halo tracks

Effect of VELO misalignment on impact parameter resolution



shifts recovered after alignment



Impact parameter resolution unchanged up to 50 μm shifts